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PSYCHOMOTOR BATTERY APPROACHES TO PERFORMANCE PREDICTION AND EVALUATION IN HYPERBARIC, THERMAL AND VIBRATORY ENVIRONMENTS:

ANNOTATED BIBLIOGRAPHIES AND INTEGRATIVE REVIEW

David J. Dixon, Melinda G. Copeland, and Charles G. Halcomb

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NAVAL BIODYNAMICS LABORATORY
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The objective of this report was to compile and integrate the literature pertaining to psychomotor performance batteries in hyperbaric/underwater, thermal, and vibration environments. Each environment is individually treated in its own annotated bibliography and integration paper. Relevant publications are summarized to reflect environment, author(s), title, purpose, methodology, significant results, conclusions, and recommendations. Abstracts of articles unavailable for review are included to provide complete coverage of each area.

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SUMMARY

It has long been recognized that the performance of complex tasks and functions is dependent upon multiple, rather than single abilities of the human operator. Since most of these complex tasks involve psychomotor performance the use of psychomotor batteries to assess and predict performance has generated much research since the first World War. All of these psychomotor battery approaches have dealt with performance in relatively normal environments. Yet, with man expanding into different environments, such as inner and outer space, it is vitally important that there be some means of assessing his performance in these special environments before systems and procedures for maximizing human performance can be developed. The present bibliographies and accompanying integration papers attempt to provide a collection and integration of the literature on performance in the special environments of hyperbaric/underwater, heat/cold, and vibration conditions.

The three-phased effort involved specifying and collecting source documents in the three environmental areas, summarizing and annotating pertinent articles, and finally compiling the bibliographies and writing the integrative review papers for each area.

Results indicate that an integrated battery approach to psychomotor performance has been undertaken in only one of the three areas (the hyperbaric/underwater environment) with the development of the SINDBAD Battery. Research efforts in the thermal and vibration environments remain somewhat disjointed with efforts concentrating on applied problems of interest rather than development of a battery approach to performance assessment and prediction.

The utility of the present effort is in providing a data base for researchers to consult for material to aid in the development of future performance assessment methods in these environments.

PREFACE

At the outset of this project the authors tried to conduct it in the way set forth in the proposal. Unfortunately, as the literature in the three areas was reviewed it quickly became apparent that no integrated battery approaches to psychomotor performance in two of the environments had been attempted. In the extreme temperature and vibratory environments research has concentrated on performance involving applied problems rather than following a generalized battery approach to performance assessment and prediction. This lack of an integrated investigative effort in these two areas leaves large gaps in our knowledge of psychomotor performance in these environments. Thus, the present paper attempted to summarize articles reporting psychomotor research involving two or more tests. The abstracts of studies in which a single psychomotor test was utilized are also included so as to provide complete coverage.

The utility of the bibliographies and integration papers in these areas is not in providing a comprehensive collection of all information concerning psychomotor performance in them, but rather in giving the reader a solid background in performance in these areas and in delineating categories of performance needing further research.

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INTRODUCTION

It has long been recognized that the performance of complex tasks and functions is dependent upon multiple, rather than single abilities of the human operator. Piloting an aircraft, for example, is intuitively dependent upon several disjoint abilities: perceptual estimation and determination, memory, detection of out-of-tolerance system states in multiple sensory modalities and fine and gross motor coordination and integration. Numerous attempts have been made over several decades to isolate underlying factors of psychomotor performance in simple and complex tasks and situations and to devise prediction schemes for such ability factors.

Probably the first expression in the literature of the need to assess complex psychomotor skills in order to predict human performance came with the work of the Italian psychologists during World War I. They attempted to select tests to identify complex skills which they thought were prerequisites for the operation of aircraft (Viteles, 1942).

The first major effort to develop a psychomotor battery to predict complex performance culminated in the U. S. Army Air Corps School of Aviation Medicine (SAM) Psychomotor Battery in the early 1940's. This effort was a natural extension of the development of the Complex Coordinator in 1929.

During World War II, the U. S. Army Air Corps selection battery underwent ten revisions in an attempt to increase its predictive power. The individual batteries utilized from four to

seven tasks with such diverse measures as finger dexterity, two-hand coordination, and complex coordination. Following World War II, except for experimental purposes, development of the SAM Battery was discontinued in 1947.

In the early 1960's, Lockheed Corporation initiated a new effort under the sponsorship of the U. S. Air Force. Among the contributors to this effort led by Dr. Jack Kraft were such experienced, and well known, psychologists as Alluisi, Chiels, Bilodeau, Passey and McLaurin. Among the distinguished consultants to the team were Christiansen and Fleishman.

The Lockheed effort resulted in the development of a battery of serially-presented tasks designed to measure such aptitudes as: simple reaction time; memory span for digits; visual and auditory signal detection; and arithmetic computations. The battery developed was never validated or used for the prediction of complex performance.

The most sophisticated extension of the Lockheed effort was the development of Alluisi's Synthetic Work Approach. Alluisi's effort appears to be a compromise between the methods of factor-analytically identified specific laboratory tests (Fleishman, 1956), and techniques of full-scale simulation. Alluisi (1966) identified seven functions as essential to the performance of skills typically demanded in a complex man-machine system. The functions were: (1) watchkeeping, (2) sensory-perceptual, (3) memory, (4) communications, (5) intellectual, (6) procedural, and (7) perceptual-motor.

The most extensive utilization of the factor analytic technique for the purposes of perceptual-motor ability assessment

is represented by Fleishman's experimental-correlational approach. Although Fleishman's approach has not resulted in a formal psychomotor battery, his identification of performance factors should prove a useful contribution to the development of future batteries.

Work by Parker, Riley, Dillon, Andrews and Fleishman in 1964 ". . . was begun under the auspices of the National Aeronautics and Space Administration to develop an integrated battery of tests to measure the primary dimensions of perceptual-motor performance . . . the objective was to package 18 separate measures of performance into an integrated console." (Parker, 1968). Using factor analytic and other multivariate techniques, an attempt was made to identify abilities appropriate for inclusion in a psychomotor test battery. The purpose of this battery was to measure perceptual-motor skills to be required during a Gemini rendezvous mission from the viewpoint of complex perceptual-motor performance.

In 1966, an effort was initiated at the Naval Aerospace Medical Institute in Pensacola Florida by Wherry, Curran and Waldeisen to develop a perceptual-psychomotor battery for prediction of Naval pilot and flight officer success in training. In 1968, an initial effort by Waldeisen and Gibson resulted in the development of a preliminary battery designed to measure three primary factors in a time-sharing context.

The foregoing has pointed to a long and continuing interest in psychomotor testing as a viable means to improve behavioral assessment and prediction in a variety of task situations. Although these efforts have provided valuable data bases and

insight into many problems in the area, they have not afforded any means of predicting an individual's capacity to fulfill complex performance requirements. From recent reviews (Christiansen, 1967; Fleishman, 1967), several reasons for this lack of closure in the area of psychomotor testing can be delineated.

The varied and often highly demanding requirements of modern systems seldom find analogous counterparts in past formulations of psychomotor skill tests. Since this is so, special environments (e. g. hyperbaric/underwater, heat/cold, and vibration) must, of necessity, be even more demanding. Thus, there is a pressing need for new psychomotor skill tests for these situations. The continued reliance on tests which place heavy emphasis on aspects such as the physical execution of responses seems particularly unwarranted in view of the changing role of man as a human operator. Future systems promise to demand less of man as simple operator and passive responder, and more of his abilities as an active monitor and decision-maker. Psychomotor tests with the greatest range of applicability will not necessarily address particularized components of a behavior sequence, but will recognize the complex chain of events from information input to response output.

Another characteristic of past approaches was the concentration upon tests which related only to the specific conditions of the particular tasks employed. Additionally, the sets of tasks which evolved permitted neither ready variations among stimulus dimensions, or the capability of reflecting the essential elements "simultaneously" involved in complex performance. This lack of flexibility, coupled with later attempts to adapt the

tasks into a unified assessment framework, have resulted in less than ad hoc utility. As noted by Fleishman (1967), the selection of laboratory tasks which can be readily translated into realistic settings will be of considerable value in the identification of homogeneous behavior categories. There is also considerable potential for tasks for which the conditions can be varied systematically to simulate the information processing load demands within a skill category. Of perhaps greater importance, these tasks would allow for the description of conditions which can be used to define the limits of an individual's performance capability.

All of the psychomotor and performance batteries mentioned above have dealt primarily with performance in relatively normal environments. However, with man expanding into the different environments of inner and outer space it is vitally important that there be some means of assessing his performance in these special environments before systems and procedures for maximizing human performance can be developed. For example, the psychomotor battery developed by Parker et. al. for NASA was to aid in performance assessment for tasks similar to those encountered in a rendezvous and docking mission in space. Similarly, the UCLA Pipe Puzzle was developed to help assess underwater performance.

Prior to the present, there has been no single comprehensive collection and integration of the literature on performance batteries in real-world or special environments, more specifically hyperbaric/underwater, hot/cold, and vibration environments. It is important that researchers in these areas have a

single integrative data base from which to draw source material to aid in the development of future performance assessment methods.

The purpose of the present effort was to collect, summarize and integrate source material concerning the development, evaluation and validation of psychomotor performance test batteries designed for evaluation and prediction of human performance in three types of special environments: hyperbaric, extreme temperatures and vibration. Summarization of the source material is presented in three annotated bibliographies: one concerned with battery performance-prediction approaches for underwater and dry-hyperbaric conditions, a second relating to battery approaches with hot or cold conditions and a third reviewing psychomotor battery efforts under conditions of whole-body vibration. Each of the bibliographies was prepared as a separately-usable entity.

An integration of performance battery approaches within these special environments precedes each bibliography. This integration was to have drawn together the findings of various efforts in an attempt to relate the successes and attempts of performance prediction by psychomotor batteries from one area to that of others, and to have defined potentially useful efforts which had not yet been made. Also, the integration was to have attempted to delineate the potential applications of general purpose performance batteries in predicting human performance in special environments. However, in reviewing the three environmental areas, it was discovered that a genuine battery approach had been developed in only one environment--the hyperbaric/underwater

environment. SINDBAD (Systematic Investigation of Diver Behavior at Depth) was the only psychomotor battery to have been developed specifically for assessing and predicting performance in a special environment. In the other two environments (i.e. thermal and vibratory) effects at developing specific batteries appear to have been neglected in favor of dealing with individual applied problems involving one to several psychomotor factors. Thus, the present paper deals only with available articles which involve two or more psychomotor performance factors. Author's abstracts are presented for articles which were not available. (This problem is discussed more fully in the Discussion Section).

METHOD

A three-phased approach was used in developing the following review papers and bibliographies. The first phase was devoted to the specification and collection of source documents for the three environments under study. Phase Two was concerned with the summarization of the source documents in a form appropriate for inclusion in the three annotated bibliographies. The last phase encompassed the final compilation of the annotated bibliographies and the preparation of the integration/review paper.

Phase One: Data Base Specification and Source Document Acquisition

In this phase, source documents relating to battery prediction approaches in the three special-environment target areas were identified and collected. Computerized searches of relevant data bases (i.e. NTIS and Psychological Abstracts) were performed, using data base sort-and-merge and direct keyword techniques. Follow-up searches of material referenced in various summaries and reviews already "in-house" were performed parallel to the

computerized literature searches. In addition, specialized sources were tapped for complete coverage of the literature in one particular environment. The Undersea Medical Society, Inc. was commissioned to search their extensive files for any references concerning psychomotor performance in the underwater/hyperbaric environment.

When an adequate specification of the data base for the bibliographies had been established (i.e. duplication of references had begun to take place) collection of the source documents (or abstracts in lieu of source documents) was begun.

Phase Two: Summarization and Annotation of Source Documents

This phase of the effort involved reading each article in its entirety, choosing salient infomation from the text and tables, and then summarizing the information sometimes employing the author's own words. The summaries of each article included (1) Environment, (2) Author, Title, and Citation, (3) Purpose, (4) Meghodology, including subject description, equipment used and procedures, (5) Significant Results, and (6) Conclusions/Recommendations. If original documents were not available or if the article included only one measure of psychomotor ability, the abstract was substituted for the summary.

Phase Three: Compilation of Bibliographies and Preparation of Review/Integration Papers

In the third phase of the effort, the final version of the three special-environment performance battery bibliographies was compiled and the integration paper on performance in these environments was prepared. The review/integration papers attempt to summarize the effects of each of the three environmental

variables upon psychomotor performance according to psychomotor factors and indicate fruitful areas for further research. Differences and similarities in psychomotor performance in the different environments are compared in the Final Conclusions Section.

DISCUSSION

The task of summarizing and integrating information relating to psychomotor battery approaches to performance prediction in the three environments was originally thought to be adequate in scope to support an effort of this size. However, as was soon discovered, little had been done in these unusual environments in the way of psychomotor battery approaches. Instead, investigators have studied the particular psychomotor factors which generated the most interest from a military and industrial standpoint (e. g. manual dexterity). The one notable exception is the SINDBAD Battery (Systematic Investigation of Diver Behavior at Depth) developed by the U. S. Navy for use in the hyperbaric/ underwater environment.

The best approach, therefore, was thought to be a summary of all articles reporting results of two or more psychomotor tests in the particular environment concerned. When investigations employing only one psychomotor test were discovered only the author's abstract was included. In general, this rule of thumb did not seem to degrade the quality or quantity of information reported since the results of most studies of single psychomotor abilities were duplicated in more comprehensive investigations which were summarized.

The review articles and specialized literature search (performed by the Undersea Medical Society) provided approximately

98 per cent of the relevant articles ultimately included in the bibliographies. The computerized literature search provided the other 2 per cent and was performed merely to insure that no gross oversights had been made. The most useful approach in searching specialized areas such as these appears to be scanning key references by well-known authors in each field and working backward from the reference sections of these sources until duplication begins.

The results of this search are given in the following annotated bibliographies, each of which was designed to be a separate useable entity. Articles are cited by both author and psychomotor factor examined in the tables at the beginning of each bibliography. (See Table 1 for a description of the psychomotor factors used.) Preceding the tables is a brief review of the effects of the particular environment on psychomotor performance.

Table 1

Description of Psychomotor Factors*

Factor	Description
1. Reaction Time	The amount of elapsed time from the onset of a stimulus to the response execution.
2. Manual Dexterity	Involves skillful, controlled rapid arm-hand coordination.
3. Finger Dexterity	Involves skillful, controlled rapid finger movements with little or no arm movement.
4. Multi-Limb Coordination	Simultaneous arm-hand and foot coordination.
5. Arm-Hand Steadiness	The ability to perform precise, accurate arm-hand movements with the arm outstretched.
6. Fine Control Sensitivity	The ability to make highly sensitive, delicate, and not over-controlled muscular movements.
7. Response Orientation	The ability to make rapid, directional, discriminations and orientations of movement patterns to select the correct movement in relation to the correct stimulus.
8. Speed of Arm Movement	Measures gross, discrete arm movements where accuracy is unimportant. Independent of reaction time.
9. Motor Kinesthesis	Involves somewhat precise postural or bodily adjustments to kinesthetic cues when the body is displaced from equilibrium.
10. Response Integration	The ability to utilize and apply cues and information from several sources into a single integrated response.
11. Spatial Relations	The ability to relate different stimuli to different responses where either are arranged in spatial order.

Table 1 (continued)

Factor	Description
12. Wrist-Finger Speed	The ability to make rapid, gross wrist-finger movements where accuracy is unimportant.
13. Position Estimation	The ability to make a somewhat precise arm-hand movement without vision.
14. Position Reproduction	The ability to repeat an arm-hand movement without vision.
15. Movement Analysis	The ability to differentiate target velocity and acceleration.
16. Perceptual Speed	The ability to make visual comparisons of several display elements.
17. Time-Sharing	The ability to perform two or more tasks simultaneously.
18. Mirror Tracing	The ability to rapidly and accurately trace a prescribed path when up-down visual feedback is reversed.
19. Aiming	The ability to execute quickly and precisely a series of accurately directed movements requiring eye-hand coordination.
20. Vigilance	The ability to monitor a display for long periods of time searching for the occurrence of an infrequent signal.

* These factors and their descriptions were taken from the following sources: Alluisi (1967), Fleishman (1967), Parker (1967).

THE HYPERBARIC/UNDERWATER ENVIRONMENT: PSYCHOMOTOR PERFORMANCE REVIEW AND ANNOTATED BIBLIOGRAPHY

INTRODUCTION

The integrated investigation of psychomotor performance in the hyperbaric/underwater environment has taken place only recently with the development of the SINDBAD test battery (Systematic Investigation of Diver Behavior at Depth) by the Navy Experimental Diving Unit. SINDBAD consists of 26 tests measuring primary mental and perceptual-motor abilities. Each of these tests has been shown to measure a unique ability through factor analytic procedures.

Most psychomotor performance underwater declines when compared to performance on dry land. This is not necessarily the case in hyperbaric environments. For this reason, performance in these two related environments will be considered separately.

THE HYPERBARIC ENVIRONMENT

The hyperbaric environment exists whenever man is exposed to more than normal atmospheric pressure (14.7 p.s.i.). This generally occurs in diving situations but also is present under experimentally-induced conditions and in certain medical situations (e.g. hyperbaric medicine). When studies on psychomotor performance are conducted under hyperbaric conditions, it is usually because the experimenters are trying to control for the many confounding stimuli encountered in the underwater environment.

Primarily two variables in the hyperbaric environment affect performance: (1) the effects of the pressure itself on the body and (2) the effects of the inert gas in the breathing mixture on the brain (generally referred to as inert gas narcosis).

In the first case, pressure effects on the body do not affect performance until very great pressures (e.g. above 10 ATA) are encountered. Under these great pressures divers begin to exhibit certain sysmptoms such as micro tremor which constitute High Pressure Nervous Syndrome (HPNS). Inert gas narcosis, on the other hand, begins to affect performance at much lower pressures (e.g. 3 to 4 ATA when nitrogen is involved).

The following sections will integrate the available literature on the effects of hyperbaric environments on the various aspects of psychomotor performance.

Manual Performance

In general, tasks involving manual performance (i.e. manual dexterity, finger dexterity, aiming, and wrist-finger speed) show a decrement in hyperbaric environments. Many investigators have reported findings supporting this assertion particularly in hyperbaric air (Adolfson, 1965; Baciu, Derevenco, Anghel, and Pastuch, 1976; Baddeley, 1966; Bennett, Poulton, Carpenter, and Catton, 1967; Kiessling and Maag, 1962; and Poulton, Catton, and Carpenter, 1964). Such decrements are primarily due to the effects of the increased partial pressure of the nitrogen in the hyperbaric air, an effect more commonly known as nitrogen narcosis. Generally, such decrements become noticeable at pressures as low as 3 ATA (Kiessling and Maag, 1962) with the deterioration increasing with the pressure. It is interesting to note that manual dexterity has been reported to decrease significantly at 4 ATA when the divers were exercising as opposed to a significant deterioration at 10 and 13 ATA when the divers were at rest (Adolfson, 1965).

In an effort to increase the operational pressures under which divers could work, helium has been used to replace nitrogen as the inert gas in the breathing mixture. This substitution has greatly increased the pressures divers could stand without manual performance degradation, however, there are also problems involved with helium-oxygen breathing mixtures. Several investigators have reported decrements in manual performance in a helium-oxygen atmosphere at very high pressures (Baddeley and Flemming, 1967; Bennett and Towse, 1971; Berghage and Reynolds, 1974; Fructus and Charpy, 1972). At lower pressures around 4 to 5 ATA the use of a helium-oxygen breathing mixture appears to prevent the effects of narcosis (Bennett, Poulton, Carpenter, and Catton, 1967).

Reaction Time

Most investigators have found that hyperbaric air environments of 4 ATA and above cause an increase in reaction time performance generally attributed to nitrogen narcosis (Kiessling and Maag, 1962; Miasnikov, Bobrov, and Shchegolev, 1971; Parker, 1970 and 1971). Frankenhaeuser, Graff-Lonnevig and Hesser (1960) found no decrement in a visual choice reaction time task and a complex 4-choice task upon exposure to pure oxygen at 3 ATA. This finding does not, however, contradict previous results with hyperbaric air since there could be no nitrogen narcosis with subjects breathing pure oxygen. Other experiments have found significantly reduced performance on reaction time tasks in helium-oxygen environments if the pressure is high enough, generally above 15 to 20 ATA (Fructus and Charpy, 1972; O'Reilly, 1977). An exception to these findings is Parker (1969) who found few

significant decrements in reaction time performance of experienced commercial divers breathing helium-oxygen at depths to 1100 feet (approximately 34 ATA).

Tracking Performance

Very little investigation of tracking performance in hyperbaric environments seems to have been done. Only one study was discovered involving tracking. Moeller and Chattin (1973) found an adaptive tracking task sensitive to the narcotic effects of air at 7 ATA. Obviously, this is an area which needs more research.

Coordination and Control Performance

Only one study concerning fine control sensitivity in the hyperbaric environment was found. Bennett and Towse (1971) used a task in a helium-oxygen environment in which tweezers were used to pick up ball bearings and place them, one at a time, in a tube. Performance was reduced at a depth of 450 feet (14.6 ATA). At depths deeper than 450 feet, fine control showed the greatest decrements probably due to increased tremors associated with the High Pressure Nervous Syndrome. The worst impairment was immediately after compression. Again, more research in these areas is needed, if for no other purpose than to serve as a baseline for underwater performance comparison.

Vigilance and Time-Sharing Performance

No studies involving vigilance or time-sharing were found in the hyperbaric environment (with the exception of the SINDBAD Battery). These are obviously important factors to be investigated as underwater work of the future becomes more complex.

Miscellaneous Performance

The incidence of arm-hand tremors associated with the HPNS has taken on great significance in research in the hyperbaric environment since tremors obviously reduce performance on any task involving the hands. Baciu, Derevenco, Anghel, and Pastuch (1976) found a significant increase in the number of static tremors in a hyperbaric environment ranging from 4 to 9 ATA. (It is assumed that the subjects were breathing hyperbaric air.) Bennett and Towse (1971) using a Tremor Transducer in a helium-oxygen environment found that tremors increased at 450 feet (14.6 ATA). A tremendous increase in tremors was reported at 600 feet (19.2 ATA) and beyond especially after each compression. Such tremors returned to low levels after several hours at depth. It was also noted that tremors appear to be subject to individual differences.

In another area of performance (Spatial Relations), Parker (1969), using a geometric forms test, found few if any significant decrements in performance at depths of 800 to 1100 feet (25.2 to 34.4 ATA).

Conclusions

There are several reasons for the lack of hyperbaric research in some of the performance areas discussed. First, many investigators have preferred to study these areas in the underwater environment since results obtained there are more readily generalizable to the applied diving situation. Second, the advent of the SINDBAD test battery in recent years has added a great deal to the body of literature on psychomotor performance in the hyperbaric/underwater environments. However, like any new test

instrument, SINDBAD was evaluated and refined by the Navy Experimental Diving Unit for several years. Results of SINDBAD's 26 tests (many of which will fill in gaps in the literature) are just now reaching the open literature.

THE UNDERWATER ENVIRONMENT

Assessing performance in the underwater environment is much more difficult than under hyperbaric conditions due to the additional variables underwater which affect performance. In addition to the effects of pressure and breathing mixture encountered under hyperbaric conditions, the underwater environment adds the variables of cold, neutral buoyancy, water resistance, restricted vision and cumbersome equipment. Thus, it is difficult, if not impossible, to generalize from the hyperbaric chamber to the operational diving situation.

Even though investigators may prefer to conduct diving research in the underwater environment due to the broader applicability of results, there are still areas of performance that have not been vigorously investigated in the underwater environment. Such categories of performance as vigilance, time-sharing, multi-limb coordination, fine sensitivity control, and tracking appear to have been neglected by investigators in favor of more readily applied tasks involving manual performance. The assessment of manual performance is indeed important since almost all diving tasks require it, but other aspects of performance are important also if basic knowledge about man's performance underwater is to stay ahead of the complex diving systems and tasks now being designed (e.g. JIM and other atmospheric pressure diving suits).

The following review and integration will point out specific areas which are in need of additional study. However, with the current Navy program of research using the integrated performance battery SINDBAD, these gaps in our information on human undersea performance will soon be filled.

<u>Manual Performance</u>

Tasks involving manual performance (i.e. manual dexterity, finger dexterity, wrist-finger speed, and aiming) generally suffer in terms of performance underwater. This degradation in performance can be linked to two major causes--a "cold effect" and a "water effect", the latter consisting of neutral buoyancy effects, the viscous resistance of the water to manual movement, and the general impairment of sensory feedback (Bowen, 1968). The "cold effect", of course, attenuates sensory feedback through numbness of the hands and also adversely affects the performance of the joints and their attendant muscles.

Many investigators have found decrements in manual performance underwater using the Screw Plate Test or a modification of it (Baddeley, 1966; Baddeley, De Figueredo, Hawkswell-Curtis, and Williams, 1969; Baddeley and Flemming, 2967; Bowen, 1968; and Stange and Wiener, 1970). Studies using other tests, such as the Ring and Peg Test, have also shown significant decrements in manual performance (Biersner, 1976; Davis, Osborne, Baddeley, and Graham, 1972). It goes without saying that more complex manual tasks also show severe decrements in performance underwater (Streimer, 1972).

<u>Reaction Time Performance</u>

Reaction time appears to suffer from the effects of cold water. Stange and Wiener (1970) found that a choice reaction

time task with a mental loading task showed a significant decrement at lower temperatures of around 50° F. This was probably due to the distraction effect of the cold.

Tracking Performance

Tracking performance also declines in the underwater environment. Bowen, Anderson, and Promisel (1966), in testing performance of SEALAB divers, found longer completion times on a Two-Hand Coordination Test in shallow water compared to dry land performance. Performance at 47° F on the same task showed a progressive slowing with a final decrement of 55 per cent (Bowen, 1968).

Coordination and Control Performance

Very little has been done in this area of performance and so an attempt at integration would be meaningless. It is important, however, to understand the effects of the underwater environment on such factors as multi-limb coordination and fine sensitivity control since sophisticated underwater systems will, no doubt, require diver performance involving these factors.

Vigilance and Time-Sharing Performance

The data in these areas is sketchy but seem to indicate no great decrease in performance underwater compared to that on dry land. Vaughan and Mavor (1972) found no degradation in a submarine depth maintenance task in cold water over a four-hour period. Other investigators have attempted to measure this type of performance underwater, but without complete success and so have not placed much emphasis on the results (Bowen, 1968).

Conclusions

Psychomotor performance underwater is subject to the effects

of many different variables: "cold effects", "water effects", diver experience, diver anxiety, environmental stress, inert gas narcosis, etc. With this great number of factors to be considered it is no surprise that underwater performance declines in comparison to dry land or hyperbaric chamber baseline performance. Manual performance is almost certainly degraded in all circumstances. The other categories of psychomotor performance are probably not as severely affected, however, it is difficult to ascertain exactly what effect the underwater environment has on their performance without more thorough investigation. Hopefully, the integrated test battery SINDBAD will yield data on tests in these areas so that satisfactory conclusions may be drawn.

Table 2

Summary of Surveyed Articles

Reference	Environment	Factors Measured
Adolfson, J. (1965)	Hyperbaric	Manual Dexterity
Bachrach, A. J. (1975)	Hyperbaric	SINDBAD
Baciu, I., P. Derevenco, Anghel, and C. Pastuch (1976)	Hyperbaric	Finger Dexterity
Baddeley, A. D. (1966)	Hyperbaric Underwater	Manual Dexterity, Finger Dexterity
Baddeley, A. D, J. W. De Figueredo, J. W. Hawkswell-Curtis, and A. N. Williams (1969)	Underwater	Manual Dexterity, Finger Dexterity
Baddeley, A. D. and N. C. Flemming (1967)	Underwater	Manual Dexterity, Finger Dexterity
Bain, E. C., III and T. E. Berghage (1973)	Underwater	SINDBAD
Bain, E. C., III and T. E. Berghage (1974)	Hyperbaric	SINDBAD
Bennett, P. B., E. C. Poulton, A. Carpenter, and M. J. Catton (1967)	Hyperbaric	Manual Dexterity
Bennett, P. B. and E. J. Towse (1971)	Hyperbaric	Manual Dexterity, Finger Dexterity, Arm-Hand Steadiness Fine Control Sensitivity, Aiming
Berghage, T. E. (1971)	Hyperbaric	SINDBAD
Berghage, T. E. and M. D. Reynolds (1974)	Hyperbaric	SINDBAD
Biersner, R. J. (1976)	Underwater	Manual Dexterity
Biersner, R. J. and B. J. Cameron (1970)	Hyperbaric	Undetermined
Bowen, H. M. (1968)	Underwater	Manual Dexterity, Response Orientation, Finger Dexterity, Time-Sharing, Vigilance

Table 2 (continued)

Reference	Environment	Factors Measured
Bowen, H. M., B. Andersen, and D. Promisel (1966)	Underwater	Manual Dexterity, Finger Dexterity, Multi-Limb Coordination
Davis, F. M., J. P. Osborne, A. D. Baddeley, and I. M. F. Graham (1972)	Underwater	Manual Dexterity
Frankenhaeuser, M., U. Graff-Lonnevig, and C. M. Hesser (1960)	Hyperbaric	Reaction Time, Mirror Tracing
Fructus, X. and J. P. Charpy (1972)	Hyperbaric	Reaction Time, Manual Dexterity
Hamilton, R. W., Jr. (1973)	Hyperbaric	Undetermined
Kiessling, R. J. and C. H. Maag (1962)	Hyperbaric	Reaction Time, Manual Dexterity
Kowal, J. P. (1970)	Underwater	Undetermined
Miasnifov, A. P., Iu. M. Bobrov, and V. S. Shchegolev (1971)	Hyperbaric	Undetermined
Moeller, G. and C. P. Chattin (1973)	Hyperbaric	Response Orientation
O'Reilly, J. P. (1977)	Hyperbaric	Reaction Time, Spatial Relations
Parker, J. W. (1969)	Hyperbaric	Reaction Time, Manual Dexterity, Spatial Relations
Parker, J. W. (1970)	Hyperbaric	Reaction Time
Parker, J. W. (1971)	Hyperbaric	Reaction Time
Poulton, E. C., M. J. Catton, and A. Carpenter (1964)	Hyperbaric	Manual Dexterity
Reilly, R. E. and B. J. Cameron (1968)	Underwater	SINDBAD

Table 2 (continued)

Reference	Environment	Factors Measured
Schreiner, H. R., R. W. Hamilton, A. D. Noble, L. A. Trovato, and J. B. MacInnis (1966)	Hyperbaric	Undetermined
Stange, P. R. and E. L. Wiener (1970)	Underwater	Reaction Time, Manual Dexterity, Finger Dexterity
Streimer, I. (1972)	Underwater	Manual Dexterity
Streimer, I., D. P. W. Turner, P. Pryor, and K. Volkmer (1971)	Underwater	Undetermined
Vaughan, W. S., Jr. (1977)	Underwater	Undetermined
Vaughan, W. S., Jr. and A. S. Mavor (1972)	Underwater	Fine Control Sensitivity, Response Integration, Perceptual Speed, Time-Sharing, Vigilance
Weltman, G., R. A. Christianson, and G. H. Egstrom (1970)	Underwater	Manual Dexterity, Finger Dexterity
Weltman, G., T. Crooks, and G. H. Egstrom (1969)	Underwater	Manual Dexterity, Finger Dexterity
Anonymous (1972)	Hyperbaric	Undetermined

Table 3

Summary of Articles by Factor Measured

Factor Measured	References
1. Reaction Time	Bachrach (1975) Bain and Berghage (1973) Berghage (1971) Berghage and Reynolds (1974) Frankenhaeuser, Graff-Lonnevig, and Hesser (1960) Fructus and Charpy (1972) Kiessling and Maag (1962) O'Reilly (1977) Parker (1969) Parker (1970) Parker (1971) Reilly and Cameron (1968) Stange and Wiener (1970)
2. Manual Dexterity	Adolfson (1965) Bachrach (1975) Baddeley (1966) Baddeley, De Figueredo, Hawkswell-Curtis, and Williams (1969) Baddeley and Flemming (1967) Bain and Berghage (1973) Bennett, Poulton, Carpenter, and Catton (1967) Bennett and Towse (1971) Berghage (1971) Berghage and Reynolds (1974) Biersner (1976) Bowen (1968) Bowen, Andersen, and Promisel (1966) Davis, Osborne, Baddeley, and Graham (1972) Fructus and Charpy (1972) Parker (1969) Poulton, Catton, and Carpenter (1964) Reilly and Camerson (1968) Stange and Wiener (1970) Streimer (1972) Weltman, Christianson, and Egstrom (1970) Weltman, Crooks, and Egstrom (1969)

Table 3 (continued)

Factor Measured	References
3. Finger Dexterity	Bachrach (1975) Baciu, Derevenco, Anghel and Pastuch (1976) Baddeley (1966) Baddeley, De Figueredo, Hawkswell-Curtis and Williams (1969) Baddeley and Flemming (1967) Bain and Berghage (1973) Bennett and Towse (1971) Berghage (1971) Berghage and Reynolds (1974) Bowen (1968) Bowen, Andersen and Promisel (1966) Kiessling and Maag (1962) Reilly and Cameron (1968) Stange and Wiener (1970) Weltman, Christianson and Egstrom (1970) Weltman, Crooks and Egstrom (1969)
4. Multi-Limb Coordination	Bachrach (1975) Bain and Berghage (1973) Berghage (1971) Berghage and Reynolds (1974) Bowen, Andersen and Promisel (1966) Reilly and Cameron (1968)
5. Arm-Hand Steadiness	Bennett and Towse (1971)
6. Fine Control Sensitivity	Bachrach (1975) Bain and Berghage (1973) Bennett and Towse (1971) Berghage (1971) Berghage and Reynolds (1974) Reilly and Cameron (1968) Vaughan and Mavor (1972)
7. Response Orientation	Bachrach (1975) Bain and Berghage (1973) Berghage (1971) Berghage and Reynolds (1974) Bowen (1968)

Table 3 (continued)

Factor Measured	References
Response Orientation (cont.)	Moeller and Chattin (1973) Reilly and Cameron (1968)
8. Speed of Arm Movement	None Found
9. Motor Kinesthesis	None Found
10. Response Integration	Bachrach (1975) Bain and Berghage (1973) Berghage (1971) Berghage and Reynolds (1974) Reilly and Cameron (1968) Vaughan and Mavor (1972)
11. Spatial Relations	Bachrach (1975) Bain and Berghage (1973) Berghage (1971) Berghage and Reynolds (1974) O'Reilly (1977) Parker (1969) Reilly and Cameron (1968)
12. Wrist-Finger Speed	Bachrach (1975) Bain and Berghage (1973) Berghage (1971) Berghage and Reynolds (1974) Reilly and Cameron (1968)
13. Position Estimation	None Found
14. Position Reproduction	None Found
15. Movement Analysis	None Found
16. Perceptual Speed	Bachrach (1975) Bain and Berghage (1973) Berghage (1971) Berghage and Reynolds (1974) Reilly and Cameron (1968)

Table 3 (continued)

Factor Measured	References
Perceptual Speed (cont.)	Vaughan and Mavor (1972)
17. Time-Sharing	Bachrach (1975) Bain and Berghage (1973) Berghage (1971) Berghage and Reynolds (1974) Bowen (1968) Reilly and Cameron (1968) Vaughan and Mavor (1972)
18. Mirror Tracing	Frankenhaeuser, Graff-Lonnevig and Hesser (1960)
19. Aiming	Bennett and Towse (1971)
20. Vigilance	Bachrach (1975) Bain and Berghage (1973) Berghage (1971) Berghage and Reynolds (1974) Bowen (1968) Reilly and Cameron (1968) Vaughan and Mavor (1972)

ENVIRONMENT: HYPERBARIC

AUTHOR: Adolfson, J.

TITLE: Deterioration of mental and motor functions in hyperbaric air.

CITATION: Scandinavian Journal of Psychology, 1965, 6, 26-32.

PURPOSE: This study investigated the effects of comparatively high ambient pressures of air upon mental and psychomotor functions. Other studies to date had not used such high pressures.

METHODOLOGY:

SUBJECTS: Fifteen male divers between the ages of 23 and 47 were used.

EQUIPMENT: The apparatus included a hyperbaric chamber, an ergometer bicycle, Vagland's test of manual dexterity, and a set of 48 simple arithmetical problems.

PROCEDURE: Subjects were tested at normal atmospheric pressure both before and after the trials under pressure. A practice period of one hour was allowed on the manual dexterity test before testing was begun. Under the exercise condition subjects pedaled the bicycle ergometer set at 300 Kpm/min. for 5 minutes before testing to reach a steady state. Pressures used were 1, 4, 7, 10, 13 and 1 ATA. The manual dexterity test involved removing 19 bolts from a vertically mounted plate and shifting them to the opposite side of the plate. Each bolt was attached to the plate by two nuts separated by a brass tube. Testing time was 7 minutes at each pressure level. The arithmetic calculation capacity test involved 48 problems in which 2 numbers were added or subtracted and multiplied by a third number. The multiplication was done first. Testing time was limited to three minutes at each pressure level.

SIGNIFICANT RESULTS: Results were analyzed by comparing normal atmospheric pressure performance with performance at each pressure level by means of a t-test. Results on the manual dexterity task showed that, with the subjects at rest, performance deteriorated significantly at 10 and 13 ATA (approximately 10 and 36 per cent, respectively). During physical work, on the other hand, a significant reduction of manual dexterity could be observed already at 4 ATA. On the calculation capacity test a significant performance decrement was obtained at 10 and 13 ATA during rest. During exercise, however, the reduction appeared already at 7 ATA. The number of calculation errors increased significantly

at 13 ATA during rest and at 10 ATA during exercise. In addition, impairment of consciousness, perceptual disturbances and memory disturbances were manifested by the subjects.

CONCLUSIONS/RECOMMENDATIONS:

(1) In general, the results confirm the well-established fact that the higher the ambient pressu is, the more intense are the defects which can b measured in mental and psychomotor performance.

(2) It was demonstrated that physical work induces a considerable enhancement of the toxic effects of hyperbaric air.

ENVIRONMENT: HYPERBARIC

AUTHOR: Bachrach, A. J.

TITLE: Underwater Performance.

CITATION: In: Bennett, P. B. and D. H. Elliott. _The Physiology and Medicine of Diving and Compressed Air Work._ Second Edition, p. 264-284, Baltimore, Williams and Wilkins Co., 1975.

Performance studies have produced contradictory results because of the lack of standardization of tests, and the difficulties of using the same tests on the surface and under water. Using performance under ideal diving conditions as a base line for evaluation is more desirable than using performance on land or in a hyperbaric chamber. Performance is affected by breathing mixture, pressure, and diver condition. The four main categories of performance to be tested are (1) cognitive, (2) perceptual-sensory, (3) psychomotor, and (4) physical proficiency. The Systemic Investigation of Diver Behavior at Depth (SINDBAD), designed at the Navy Experimental Diving Unit for wet or dry chamber dives, consists of 26 tests ranging from very simple to very complex. Factor analysis results showed that each measure was unique, and that the expected redundancy did not occur. Another approach to performance evaluation is the physiological one, which involves monitoring by telemetry such factors as heart rate, oxygen consumption, etc. Many types of stress can interact--both to potentiate and to mitigate each other. Other factors which greatly affect performance are equipment, training, practice effects, and adaptation. Subject variability and task variability must also be considered. (MFW/UMS)

ENVIRONMENT: HYPERBARIC

AUTHOR: Baciu, I., P. Derevenco, I. Anghel, and C. Pastuch

TITLE: The influence of moderate hyperbaric environment on the sensory-neuro-motor processes in man.

CITATION: Rev. Roum. Morphol. Embryol. Physiol. (Ser. Physiol.), July-Sept. 1976, 13 (3), 169-174.

Thirteen healthy male divers were repeatedly studied during the exposure to a moderate hyperbaric environment of 4 - 6, 7 and 9 ATA, in a hyperbaric chamber. The maximal duration of the exposure was 35 min, and that of decompression 90 min. As compared to the dynamics of the changes found in 14 controls, under hyperbaric conditions a significant increase in the number of static tremor, an impairment of the sensory-motor performance in O'Connor's and in the rotation test were found and also of the muscular strength and resistance to fatigue (this latter only at 9 ATA). (Authors' summary)

ENVIRONMENT: UNDERWATER & HYPERBARIC

AUTHOR: Baddeley, A. D.

TITLE: Influence of depth on the manual dexterity of free divers: A comparison between open sea and pressure chamber testing.

CITATION: Journal of Applied Psychology, 1966, 50, 81-85.

PURPOSE: This study investigated the effects of pressure at depth versus pressure in a chamber on manual dexterity as measured by the screwplate test.

METHODOLOGY:

SUBJECTS: Underwater, 12 subjects were used, 11 army divers of the Royal Engineers and 1 amateur diver. Eighteen divers were used in the pressure chamber, 16 army divers from the Royal Engineers and 2 civilian divers.

EQUIPMENT: The basic apparatus was a screwplate 6 x 12 x 1/16 inches with 32 1/4-inch holes arranged in two 4-inch squares. Each hole in the left-hand group contained a 1/2-inch cheese-head 2 BA brass screw backed by a hexagonal brass nut. The 16 holes in the right hand group were empty. A modified version of Mackworth's V test was also used. It consisted of two 12-inch perspex rulers bolted together in the middle and at one end, and separated by a 1/2-inch block of tufnol at the other end.

PROCEDURE: In all conditions, underwater subjects carried out both the screwplate test and the V test. During the V test the subject averted his face and his index finger was placed on the rulers by the experimenter. Six readings were taken in each condition, 3 ascending and 3 descending runs with the order randomly interspersed. On the screwplate test subjects were required to transfer the bolts from the left-hand group of holes to the right-hand group of holes as fast as possible and tighten them finger tight. All subjects performed the tasks seated in low canvas chair.

In the underwater condition, all 12 subjects performed each of the three conditions; above the surface, 5-12 feet below the surface, and 100 feet below the surface. In the hyperbaric, chamber, all 18 subjects performed the three conditions; pressure equivalent to depths of 0, 10, and 100 feet.

SIGNIFICANT RESULTS: In the underwater condition, the following results were observed:

(1) Significant differences in time to completion were found between all three depths. It took longer for subjects to complete the task as 10 feet than at the surface and longer still at 100 feet.
(2) A significant increase in the number of loose nuts was observed as depth increased.
(3) Amount of diving experience and practice effects over trials were not statistically significant variables.
(4) No significant change in tactile sensitivity was noted with increased depth.

In the hyperbaric condition, the following results were noted:

(1) A significantly longer time to complete the task was taken at 100 feet than at surface pressure (5.5 per cent longer). Differences between 10 feet and 100 feet and between surface pressure and 10 feet were not significant.
(2) Accuracy, in terms of number of loose nuts, was consistently higher in the dry versus the wet condition.

Comparison of wet and dry conditons indicates that the mean impairment score underwater was 19.8 per cent while in the chamber it was only 4.6 per cent, a significant difference.

CONCLUSIONS/RECOMMENDATIONS:

(1) The results underwater suggest that manual dexterity is impaired to a much greater extent than the 7.9 per cent in a hyperbaric chamber shown by Kiessling and Maag (1962). This implies that results obtained in a dry pressure chamber can not validly be generalized to performance under water.
(2) The lack of change in tactile sensitivity with increased depth makes it seem unlikely that the impairment in manual dexterity at depth was due to finger numbness.
(3) The influence of pressure on manual dexterity underwater is much greater than that of pressure in a hyperbaric chamber. This is probably due to the stresses and handicaps the diver incurs underwater, e. g. cumbersome equipment, restricted vision, and relative weightlessness, etc.

ENVIRONMENT: UNDERWATER

AUTHORS: Baddeley, A.D., De Figueredo, J.W., Hawkswell- Curtis, J. W. and Williams, A. N.

TITLE: Nitrogen narcosis and performance under water.

CITATION: Ergonomics, 1969, 11, 157-164.

PURPOSE: Past investigations have demonstrated decreased performance of divers breathing compressed air at depths of 100 feet or more due to nitrogen narcosis. Since the amount of decrement appears to be task-dependent, the present investigation examined a range of tasks underwater to determine the effects of narcosis on specific tasks.

METHODOLOGY:

SUBJECTS: Subjects were 18 young male divers from various service and university expeditions.

EQUIPMENT: Apparatus included a digit copying task, a sentence comprehension test, and the screwplate test.

PROCEDURE: All subjects performed the three tasks twice at depths of 5 feet and 100 feet for a total of four times. Order was counterbalanced as a control procedure.

In the digit copying task, subjects were required to copy random digits on to a 16 x 9 inch roughened formica sheet with a soft pencil. Subjects were instructed to write as fast as possible without making mistakes and to look only at the digits to be copied and not what they were copying. The test lasted one minute. The dependent measure was the height of the digits. The sentence completion task required the subjects to read a series of sentences describing the order of two letters, A and B, which followed the sentence. The subject responded by checking True or False to indicate whether the sentence correctly described the relationship of the letters. The test comprised all 64 possible combinations of the following six binary conditions: positive or negative, active or passive, true or false, precedes or follows, A or B mentioned first, letter pair AB or BA. Subjects were allowed 3 minutes to complete as many items as possible. The dependent measures were number of sentences attempted and per cent errors. The screwplate test of manual dexterity required subjects to transfer 16 2 B.A. cheese-head brass nuts and bolts from one end of a 12 x 6 inch brass plate to the 16 holes at the other end. The dependent measures were time to completion, number of screws lost, and number left loose.

SIGNIFICANT RESULTS: Results were as follows:

(1) A significant increase in digit size at the 100 foot depth compared to the 5 foot depth was noted, however the increase was not significant on the second trial.

(2) On the sentence comprehension test, analysis of the mean number of sentences correct indicated a significant drop in speed at depth, however, no significant difference in errors at depth was observed.

(3) The results on the screwplate test appeared to be subject to considerable uncontrolled variability, however, a small but significant increase in completion time at depth was found by combining the two trials at each depth. A 28 per cent decrement for performance underwater versus in a dry environment was found.

CONCLUSIONS/RECOMMENDATIONS: The authors came to the following conclusions:

(1) A drop in efficiency on all three tests was demonstrated although the decrement on the two manual dexterity tests was small compared to the test involving reasoning. This supports the results of previous studies which demonstrated that intellectual tasks are most impaired by nitrogen narcosis.

(2) The present study did not show as great a decrement in performance at depth as previous studies when compared to performance at similar depths in hyperbaric chambers. It is thought that this was due to the ideal conditions of the present study (clear, calm water, etc.) compared to previous studies which were conducted under more stressful circumstances.

ENVIRONMENT: UNDERWATER

AUTHORS: Baddeley, A.D., and Flemming, N.C.

TITLE: The efficiency of divers breathing oxy-helium.

CITATION: Ergonomics, 1967, 10, 311-319.

PURPOSE: This study was conducted to determine the relative efficiency of a diver breathing air versus a diver breathing oxy-helium.

METHODOLOGY:

SUBJECTS: Eight members of the Cambridge University Underwater Exploration Group served as subjects in Experiment 1 while seven experienced amateur divers and five diving instructors from the Royal Engineers Diving School served as subjects in Experiment 2.

EQUIPMENT: Apparatus for the Arithmetic Test included sums comprised of 5 two-digit numbers printed on paper and attached to formica boards with waterproof glue. The Screwplate Test consisted of 16 2 B.A. brass nuts and bolts which were to be transferred from holes in one end of a 12 x 6 inch brass plate to the 16 holes at the other end.

PROCEDURE: In Experiment 1, eight divers performed the two tasks twice at a depth of 6-10 feet and twice at 200 feet. On one dive they breathed a 25% oxygen and 75% helium mixture. Divers were tested in pairs at each depth with one breathing air and one breathing oxy-helium. Upon reaching the bottom, the divers signalled the surface and then began the 5-minute Arithmetic Test. Dependent measures were number of problems completed and errors made. The Screwplate Test was begun after the Arithmetic Test and each diver was timed independently on the surface. Dependent measures were the amount of time to completion and the number of loose nuts. The order of the tests was counterbalanced to control for sequence effects

In Experiment 2, the same tasks were used in a hyperbaric chamber with all divers breathing oxy-helium at surface pressure and at 200-foot pressure. Subjects were run in groups of 2 or 3.

SIGNIFICANT RESULTS: Results of Experiment 1 were as follows:

(1) There was no difference in performance between the air and oxy-helium on any test at the 10-foot level.
(2) On the Addition Test at 200 feet, the number of problems completed was reduced for both air (19.9% decrement) and oxy-helium (14.8% decrement). The mean number of errors at 200 feet was considerably greater on air (21.07%) versus oxy-helium (7.62%).

(3) On the Screwplate Test divers were significantly slower at 200 feet than at 10 feet regardless of breathing mixture. Divers were slower on air than oxy-helium but not at a significant level. At 200 feet, divers on air tended to lose more screws than divers on oxy-helium.

Results of Experiment 2 showed:

(1) On the Addition Test, there was a significant reduction in the number of problems completed at 200-foot pressure compared to the surface, but there was no difference in the number of errors made
(2) The Screwplate Test took 10 per cent longer to do at 200-foot pressure compared to the surface and there was a tendency for more screws to be left loose (10.94% more loose screws) than at surface pressure.

<u>CONCLUSIONS/RECOMMENDATIONS</u>: The authors concluded that divers at 200 feet work more quickly and more accurately when breathing oxy-helium than when breathing air. They also conclude that the stresses inherent in the diving environment (e.g., cold, wetness, weightlessness) interact with narcosis to reduce performance since a decrement of 10 per cent in manual dexterity in a pressure chamber becomes a 30 per cent decrement in the open sea, while rate of addition changed only 10-15 per cent. This leads one to believe that manual performance at depth suffers more than cognitive performance.

ENVIRONMENT: UNDERWATER

AUTHOR: Bain, E. C., III and T. E. Berghage

TITLE: Preliminary evaluation of SINDBAD tests.

CITATION: U. S. Navy Experimental Diving Unit, Oct. 3, 1973.

This informal report gives a brief description of each of the tests which can be administered by SINDBAD (System for Investigation of Diver Behavior at Depth), which was installed at the U.S. Navy Experimental Diving Unit in 1968. Results of tests as undergone by 27 subjects for the first 14 tests, and 16 subjects for the remaining eight tests, are given and analyzed statistically. Tests are designed to measure the following abilities: flexibility of closure; perceptual speed; spatial orientation; finger dexterity; manual dexterity; reaction time; time interval estimation; wrist-finger speed; associative memory; induction; number facility; spatial scanning; visualization; control precision; multilimb coordination; response orientation; system equalization; vigilance; memory span; time sharing; visual monitoring. (MFW/UMS)

ENVIRONMENT: HYPERBARIC

AUTHORS: Bain, E.C., III, and Berghage, T.E.

TITLE: Evaluation of SINDBAD tests.

CITATION: Research Report 4-74, Navy Experimental Diving Unit, Washington, D.C., June, 1974, Ad #781-643.

PURPOSE: The purpose of this study was twofold: (1) to evaluate the adequacy of the various tests in the SINDBAD (Systematic Investigation of Diver Performance at Depth) performance test battery and (2) to establish normative dry baseline data on Navy First Class Divers.

METHODOLOGY:

SUBJECTS: Twenty-seven U.S. Navy first class divers were used as subjects. They ranged in age from 26 to 41 years with a median age of 31.6 years.

EQUIPMENT: A hyperbaric chamber was used in which to conduct the tests and the various apparatus associated with the SINDBAD battery was used. This apparatus primarily included a back projector screen, an oscilloscope, and a digital display. The digital display and oscilloscope were located outside the chamber and were viewed through a viewing port. Slide material was projected through this port onto a back projector screen located inside the chamber. An experimenter's console automatically scored the subjects' responses.

PROCEDURE: The 22 tests were administered in two sections; each section having a total test time of approximately one hour. All 22 tests were administered to each test subject twice, the first administration being for orientation and to obtain reliability coefficients with the second administration. During the actual testing, the subject was seated at a small work bench in front of the chamber view port. The chamber pressure was at one atmosphere absolute (normal atmospheric pressure).

The tests and their associated factors are:

Test	Factor
(1) Hidden Patterns	Flexibility of Closure
(2) Shortest Road	Length Estimation
(3) Number Comparison	Perceptual Speed
(4) Card Rotation	Spatial Orientation
(5) Key Insertion	Finger Dexterity
(6) Wrench and Cylinder	Manual Dexterity
(7) Visual Reaction Time	Reaction Time
(8) Internal Reproduction	Time Interval Estimation
(9) Tapping	Wrist-Finger Speed

(10)	Word-Number	Association Memory
(11)	Letter Sets	Induction
(12)	Addition, Subtraction, Multiplication, Division	Number Facility
(13)	Choosing a Path	Spatial Scanning
(14)	Surface Development	Visualization
(15)	Position Control	Control Precision
(16)	Two-hand Tracking	Multi-Limb Coordination
(17)	Choice Reaction Time	Response Orientation
(18)	Rate Control	System Equalization
(19)	Visual Signal Detection	Vigilance
(20)	Visual Digit Span	Memory Span
(21)	Track and Monitor	Time Sharing
(22)	Terminal Digits	Visual Monitoring

SIGNIFICANT RESULTS:

(1) No real high correlations were found among the 22 tests of the battery. This indicates test independence.
(2) The factor analysis showed that each theoretical factor had one and only one test with which it was highly correlated.
(3) Reliability coefficients on some of the tests were low, most notably on the following tests: Hidden Patterns, Shortest Road, Number Comparison, Card Rotations, Key Insertion, Wrench and Cylinder, and Letter Sets.

CONCLUSIONS/RECOMMENDATIONS: The authors emphasize that the reliability data is tentative at best due to procedural changes, etc. The low reliabilities on some of the tests could, of course, have accounted for the lack of intercorrelations among the tests. The authors suggest that the data indicates the tests are separate, independent measures of underlying human abilities, but that changes in instructions, test administration and equipment need to be made before SINDBAD can reach its full potential.

ENVIRONMENT: HYPERBARIC

AUTHORS: Bennett, P.B., Poulton, E.C., Carpenter, A., and Catton, M.J.

TITLE: Efficiency at sorting cards in air and a 20 per cent oxygen-helium mixture at depths down to 100 feet and in enriched air.

CITATION: Ergonomics, 1967, 10, 53-62.

PURPOSE: The present experiment was designed to determine if the decrement in a card sorting task at depth was due to the high partial pressure of nitrogen or oxygen, or if other factors were involved.

METHODOLOGY:

SUBJECTS: The subjects were 80 men, aged 18 to 56 years, from the Royal Navy with varying experience in diving.

EQUIPMENT: A pressure chamber at the Royal Navy Physiological Laboratory was used, as well as two card sorters. The card sorters were boxes with slots for each of the four suits of playing cards.

PROCEDURE: Eight groups of subjects were used and all groups sorted cards twice. Groups A1, A2, and A3 breathed air and worked once at depth and once on the surface. Groups A1 and A3 both performed at surface pressure and 100 feet (4 ATA), but in opposite orders. Group A2 worked first at a depth of 33 feet (2 ATA) and then at the surface. Groups H1, H2, and H3 worked at the same depth as the A-series groups, but breathed oxy-helium instead of air. Groups 01 and 02 worked at surface pressure first in an artificial atmosphere consisting respectively of 40 per cent and 80 per cent oxygen in nitrogen, and then in air. Two subjects were run at one time. They first breathed the gas mixture for a few minutes and then were compressed to the proper pressure. The subjects practiced the card sorting task for 2 minutes before the 10 minute test trial. Three dependent measures were recorded: errors over trial, seconds per card and percent slow responses (i.e., over 2.5 seconds).

SIGNIFICANT RESULTS:

(1) Significantly more errors were made at a depth of 100 feet in air than at the surface in air ($p < .02$).
(2) No significant decrement in performance was noted at a depth of 33 feet when breathing air or at either depth when breathing oxy-helium.
(3) Oxygen enriched mixtures breathed at the surface did not affect performance either.
(4) On the first trial, all groups working at depth sorted faster and less accurately on the average than all groups working at the surface ($p < .05$). There was also a carry over of the rate of work from the first trial to the second ($p < .05$).

CONCLUSIONS/RECOMMENDATIONS: The finding of increased errors at depth is in line with the results of previous researchers. However, the increased sorting speed at depth is not consistent with previous findings and is accounted for in terms of the increased arousal level in the subjects caused by the chamber noise level (SPL of 95 dB) and temperature (Effective Temperature of 81° F.).

ENVIRONMENT: HYPERBARIC

AUTHORS: Bennett, P.B., and Towse, E.J.

TITLE: Performance efficiency of men breathing oxygen-helium at depths between 100 feet and 1500 feet.

CITATION: Aerospace Medicine, 1971, 42, 1147-1156.

PURPOSE: The present study was carried out to determine the aetiology of the High Pressure Nervous Syndrome (HPNS) and to determine if man could safely dive to depths greater than 1200 feet. Investigators also tested the effects of an oxygen-helium breathing mixture on performance to determine if it caused inert gas narcosis at depth.

METHODOLOGY:

SUBJECTS: Two subjects from the Royal Naval Physiological Laboratory staff were used. Subjects were 21 and 27 years old with one relatively inexperienced in diving and the other with considerable recreational diving experience. One of these divers was replaced during the 100 foot test dive, but later took part in the 1500 foot dive.

EQUIPMENT: A two-compartment pressure chamber was used. Performance test equipment included a Ball Bearing Test, a Tremor Transducer, a Purdue Peg Board Test, a Towse Touch Test, the Wechsler Bellevue Digit Symbol Test (Visual Analogies), an Arithmetic Test, and a Personal Comment Check List.

PROCEDURE: Test dives to 100, 300, and 450 feet for 24 hours each were conducted first to allow the subjects and research team to become familiar with the techniques to be used in the 1500 foot dive. Partial presentation of the performance battery was accomplished on these test dives. For the 1500 foot dive, stages of 24 hours were spent at 600 feet and 1000 feet and 22 hours at 1300 feet with one hour stages at 1100 feet, 1200 feet, and 1400 feet, culminating in 10 hours at 1500 feet. Compression rate on all dives was 16-17 feet per minute.

The performance tests administered to the subjects included:

(1) Ball Bearing Test - The subject was required to pick up ball bearings with tweezers and place them, one at a time, in a tube. Time for the test was one minute and the score was the number of balls in the tube.
(2) Tremor Transducer - A Specialized Laboratory Equipment TREM 1 Tremor Transducer was attached by a rubber sheath to the middle index finger of the subject, who held his forearm and hand stretched out straight in front, while his elbow rested on his leg. The transducer measured the velocity of the postural tremor.

(3) Purdue Peg Board Test - In one minute as many pegs and washers as possible had to be assembled in holes on a board. The score was the number of parts assembled; each complete item consisting of one peg, two flat washers and a spacer for a total item score of 4.
(4) Towse Touch Test - While blindfolded, in one minute the subject sorted two sizes of ball bearings which also had different textures. The score was the sum of correct balls sorted in the right and left trays minus the errors.
(5) Wechsler Bellevue Digit Symbol Test (Visual Analogies) - The subject was required to relate symbols to a set of numbers from 1 to 9 given in a key. The score was the number of correct answers in one minute.
(6) Arithmetic Test - In two minutes the subject did as many problems as possible consisting of two digit numbers multiplied by one digit numbers. The score was the number of problems correct and the number attempted.
(7) Personal Comment Check List - This deep diving questionnaire was completed by each subject at regular intervals, together with their assessment of the environmental and pressure effects upon them.

SIGNIFICANT RESULTS: In general, the results indicated the following:

(1) At the 100 foot depth, one subject showed some decrease in manual dexterity performance during the first hours at this depth.
(2) At 300 feet no serious impairment in efficiency on the various performance tests was observed.
(3) At 450 feet the tests of manual dexterity of one subject were the most affected with the sensitive Ball Bearing and Touch Tests reduced the most. There was a small decrement on the Peg Board Test. An increase in tremors was the most probable cause of these decrements.
(4) At the deeper depths of 600 feet and beyond tremors of one subject increased tremendously with each compression (up to 500% of pre-diving levels) but returned to relatively stable low levels after several hours at each particular depth. The other subject appeared more tolerant of the pressure and did not show a very great increase in tremor activity.
(5) At depths deeper than 450 feet, the fine manual dexterity tests (such as the Ball Bearing, Touch, and Purdue Peg Board Tests) showed the greatest performance decrement. The worst impairment was immediately after compression. Mental tests such as the Arithmetic and Visual Analogies Tests were virtually unaffected. As at 600 feet, these declines in performance efficiency appeared to be due to the tremors.

CONCLUSIONS/RECOMMENDATIONS: The authors conclude that:

(1) Helium does not induce signs and symptoms of narcosis similar to those produced by increased pressure of nitrogen and argon.

(2) At 1500 feet the tests of mental performance showed no significant decrement indicating no helium narcosis. However, signs and symptoms of HPNS did occur, including "tremors" which were responsible for a decrement in manual dexterity and motor coordination.

(3) In general these decrements were not much more severe at 1500 feet than at 450 feet.

(4) The incidence of tremors could be decreased in future deep dives by careful selection of subjects since there appear to be wide individual differences in compression tolerance.

ENVIRONMENT: HYPERBARIC

AUTHOR: Berghage, T. E.

TITLE: An integrated measurement system for testing human performance in hyperbaric environments.

CITATION: In: Abstracts of BuMed-ONR sponsored Navy-wide workshop in high pressure biomedical research, U. S. Submarine Base, Groton, Conn., May 1971, p. 29, Published by the Naval Submarine Medical Research Laboratory, 1971.

Abstract only. Entire item quoted: This paper describes an integrated measurement system that has been developed for the U.S. Navy Experimental Diving Unit for testing diver performance. The system can be used in a wet or dry environment at pressures up to 445 psi, equivalent to a depth of 1000 feet of sea water. The 26 tests included in the system were selected to measure man's cognitive and perceptual-motor abilities. Their inclusion in the system was based upon: (1) their factorial purity, (2) test reliability and validity, (3) anticipated future diver activities, and (4) engineering constraints. As the divers perform the experimental tasks their responses are automatically scored and punched into . computer data cards. This measurement system provides a flexible new tool for research related to human performance in hyperbaric environments.

ENVIRONMENT: HYPERBARIC

AUTHOR: Berghage, T. E. and M. D. Reynolds

TITLE: Human cognitive and perceptual-motor performance in a helium-oxygen 49.5 ATA environment.

CITATION: In: Abstracts, Biomedical research and underwater breathing apparatus evaluation dives 10 to 1600 feet, April 1-2, 1974, p. 18, U. S. Navy Experimental Diving Unit, Report NEDU-23-74, 1974.

The SINDBAD performance testing system was used during the U.S. Navy 1600-foot saturation dive. Perceptual skill, cognitive ability, and motor performance were tested at 1000, 1300, and 1600 fsw. Perceptual skills were little changed, cognitive ability deteriorated significantly, and motor performance deteriorated slightly, except in the case of a task that required smooth gross motor movements of both arms. It was concluded that at 1600 fsw, tasks requiring fine motor dexterity and fast intellectual response present the greatest difficulty. (MFW/UMS)

ENVIRONMENT: UNDERWATER

AUTHOR: Biersner, R. J.

TITLE: Motor and cognitive effects of cold water immersion under hyperbaric conditions.

CITATION: Human Factors, 1976, 18, 299-304.

Motor and cognitive tests were administered to four Navy divers under dry baseline conditions, in warm and cold shallow water, and again in cold water at 183 m. It was found that water resistance, cold water, and prolonged exposure to cold water at depth resulted in significant decrements in motor performance. None of these factors, however, consistently or reliably impaired cognitive performance. Those cognitive impairments which were found could probably be accounted for by impaired motor performance. The motor effects of prolonged exposure to cold water at 183 m may be related to either severe heat debt or CO_2 retention. These results indicate that present heating techniques are inadequate to protect divers from significant motor impairments after entering cold water at any depth, and from additional decrements after exposure to cold water for an hour at 183 m.

ENVIRONMENT: HYPERBARIC

AUTHOR: Biersner, R. J. and B. J. Cameron

TITLE: Cognitive performance during a 1,000-foot helium dive.

CITATION: Aerospace Medicine, 1970, 41, 918-920. Also published as NEDU-RR-10-70, 7 p., 1970.

Five divers performed three cognitive tasks at six intervals during a saturation dive to a simulated depth of 1,000 fsw. Tasks included an associative memory test, an embedded figures test, and a cognitive interference test. Each of the three tests was also administered to a surface control group at intervals approximating those of the experimental group. None of the three tasks produced statistically significant differences between experimental and control groups, nor did performance variations relate in any systematic way to conditions of the dive. It was concluded that helium is not narcotic at 1,000 fsw, and that performance variability reflected individual adjustment to the hazardous conditions of the dive. (Authors' abstract)

ENVIRONMENT: UNDERWATER

AUTHOR: Bowen, H. M.

TITLE: Diver performance and the effects of cold.

CITATION: Human Factors, 1968, 10, 445-464.

PURPOSE: The purpose of the study was to measure performance as affected by three environmental conditions: dry land, warm water, and cold water conditions.

METHODOLOGY:

SUBJECTS: Sixteen subjects, most of whom were employees of Dunlap and Associates, were used. Diving experience ranged from 6 weeks to 10 years.

EQUIPMENT: Diving equipment included a standard full-body wet suit and SCUBA gear. Test equipment included a version of the Mackworth "V" test, a hand dynamometer to measure grip strength, a Pegs and Ring Test, a Screw Plate Test, a Two-Hand Tracking Test, a Group Assembly Test, a Mental Arithmetic Test, a Symbol Processing Test, the Set Exceptions Test (a simple problem-solving test), the Clock Test (to measure short-term memory), and Tracking/Audio Vigilance (a multiple or time-sharing task). Several of these tests were not standard tests of diving performance and need explanation.

In the Pegs and Ring Test the subject took rings one at a time from a peg at the bottom of a board and placed them on each of 12 pegs arranged in a rectangular pattern at the top of the board. The rings then had to be removed and placed back on the bottom peg. Performance was with one hand and the score was the time to completion. The Two-Hand Tracking Test required the subject to move a peg along a twisting track by rotating two knobs which moved the peg in the X and Y coordinates. The score was average time to completion. The Group Assembly Task required a group of three or four men to cooperate in assembling a structure. Performance was scored in terms of time to assemble and a rating of firmness and symmetry of the structure. The Symbol Processing Test required a subject to find in a matrix code the numerical values associated with several colors and perform certain arithmetic operations on the values. Scoring was in terms of time required to complete four problems and the number correct. In the Set Exceptions Test the task was to discover and indicate which one of five numbers did not have a common denominator with the others. The Clock Test required the subject to memorize the times on 8 clock faces in a one minute inspection period and record

his recall on a similar set of blank clock faces after a 30-second waiting period. The Tracking/Audio Vigilance Task required the subject to perform the Two-Handed Tracking Test and at the same time to listen for repeated numbers in a series of spoken numbers.

PROCEDURE:

All subjects were given unlimited practice on the tests prior to collection of the dry-land control data. Underwater testing was conducted at two test sites: a water tower 8 x 25 feet and a flooded quarry using a platform lowered from a derrick. Warm and cold water conditions were 47° and 62° F at the flooded quarry. Depth never exceeded 36 feet to control for the effects of narcosis.

The general procedure was for the divers to "splash-in" and position themselves at the test station. They then removed their gloves and began the tasks. Task sequence was counterbalanced and total exposure time averaged approximately 30 minutes. Measurements on most tests were taken after a short exposure (2-3 minutes) and a long exposure (15-25 minutes). Urine temperatures were obtained at the completion of the dive to measure central body temperature.

SIGNIFICANT RESULTS: The following results were obtained:

(1) On the "V" test a fairly steady drop in tactile sensitivity was produced with lowered temperature. Long exposure combined with the lowest water temperature (47° F) produced a decrease of 336 per cent from the dry land measure.

(2) Grip strength showed a 14 per cent decrease under the long exposure cold water condition when compared to dry land performance.

(3) Performance on the Pegs and Rings Test decreased 60 per cent under the cold water, long exposure condition when compared to dry land performance.

(4) On the Screw Plate Test, the data indicate a progressive slowing of performance as a function of water temperature, the loss being 30 per cent at the coldest water temperature. There were no significant differences between short and long durations.

(5) Data on the Two-Hand Tracking Test indicates a progressive slowing of performance as a function of water temperature with a 55 per cent decrement at 47° F. No statistical differences were noted between short and long exposure times.

(6) On the Group Assembly Task, no significant differences in performance were indicated for the dry land, warm, and cold water conditions.

(7) On the Mental Arithmetic Test the data indicated a

significant decrease in the number of problems attempted during both the warm and cold water conditions compared to dry land. The number of problems correct, however, did not change under any of the temperature conditions. Exposure had no significant effect on either variable.

(8) On the Symbol Processing Test, performance was significantly less accurate in the water than on dry land. This loss in accuracy amounted to 12 per cent and was not due to exposure or water temperature.

(9) On the Set Exceptions Test, significantly more omissions were made at the cold water condition. However, the correct/attempted ratio was not significant.

(10) Performance on the Clock Test, as measured by the ratio of number correct to number attempted, decreased in the water conditions at both temperatures. The loss amounted to a 22 per cent decrease which was significant at the .025 level.

(11) Performance on the original Tracking/Audio Vigilance Test (Multiple Task Test) could not be ascertained due to problems with the SCUBA exhaust bubbles interfering with the audio task. When the time between audio stimuli was increased no differences in performance under the various conditions were noted.

CONCLUSIONS/RECOMMENDATIONS:

(1) With cooling, sensation and strength are considerably impaired.

(2) Psychomotor skills are impaired by the cold partly as a consequence of peripheral attenuation and partly through some attenuation of control processes underlying skillful activity.

(3) Mental performance is impaired provided the tasks are sufficiently demanding in terms of concentration and short-term memory requirements.

(4) Two causes of performance impairment are thought to affect divers--a "water" effect and a "cold" effect. The former is composed of several factors, among them neural buoyancy, viscosity of the water, reduced sensation, encumbrance by equipment, and attention to diving procedures necessary to assure personal safety. The "cold" effect is superimposed on the "water" effect and acts both directly in spoiling psychomotor performance, and, more indirectly, on central processes probably by causing distraction from the task at hand.

ENVIRONMENT: UNDERWATER

AUTHORS: Bowen, H. M., Andersen, B., and Promisel, D.

TITLE: Studies of divers' performance during the SEALAB II Project.

CITATION: Human Factors, 1966, 8, 183-199.

PURPOSE: The purpose of this study was to illuminate the effects of pressure and the environment on performance underwater and indicate the type and amount of behavior loss due to diving conditions other than narcosis.

METHODOLOGY:

SUBJECTS: Three 10-man teams participated in the study.

EQUIPMENT: Apparatus included: (1) Strength Test--two torque wrenches mounted on the shark cage of the SEALAB II structure, one horizontally and one vertically, (2) Triangle Test--three one-foot lengths plus nuts, washers and bolts with which to join them into a triangle, (3) Two-Hand Coordination Test--a mechanism box with a 2-inch knob on either side which controlled one axis of movement of a peg on top of the box; 9 templates containing tracks of varying difficulty through which the peg was to be moved, (4) Group Assembly Test--a structure composed of 84 separate pieces which represented the type of light-duty structure divers might have to manipulate.

PROCEDURE: All tests were performed outside the SEALAB II habitat at a depth of 205 feet. Divers breathed a tri-gas mixture of helium, nitrogen, and oxygen. The divers performed the following four tests of psychomotor ability as time permitted. The Strength Test consisted of two torque wrenches attached to the shark cage--one in a vertical position to measure "pull" and the other in a horizontal position to measure "lift". The Triangle Test consisted of assembling three lengths together to form a triangle using two washers, a bolt, and a nut on each joint. To make the task more difficult two sizes of bolt were used (large or small) and the lengths either had symmetrical or asymmetrical holes in the end. In the latter case it could be arranged so that any piece fit every other one or only one certain piece would fit another one. Thus, four versions of this test, varying in difficulty, could be administered. The Two-Hand Coordination Test consisted of moving a peg along a track by means of two knobs which controlled the position of the peg in X, Y coordinates. The test required the continuous visual monitoring of the position of the peg in relation to the track and the coordination of rotary movements between the two hands. Nine possible templates or tracks could be used which varied in difficulty. The Group Assembly Test required the divers

to work together in teams of four in assembling a structure, portrayed to the subjects by a perspective drawing, from lengths of pipe and appropriate connectors.

SIGNIFICANT RESULTS: Results on the four psychomotor tasks were as follows:

(1) Divers appear to suffer only a slight loss in the maximum force that can be applied to a torque arm (9 percent decrement) underwater. A larger decrement (21 percent) was noted on the stretch test of strength using the vertical torque arm.
(2) The average percentage increase in time taken to assemble the Triangle Test with respect to dry land conditions was 21 percent for shallow water conditions and 49 percent for SEALAB conditions.
(3) Data on the Two-Hand Coordination Test were unreliable due to equipment malfunction, however, the shallow water trials were longer than the dry land tests.
(4) Data for the Group Assembly Test cannot be interpreted since only one observation was made under SEALAB conditions.

CONCLUSIONS/RECOMMENDATIONS: The authors readily admit that while the data are not conclusive, a general pattern of results suggests itself.

(1) Simple, short-term tasks, which can be conducted according to a simple plan (e.g. the strength test and certain of the tasks undertaken in the simulated salvage operations) suffer very little impairment as compared with dry-land conditions.
(2) As soon as a task becomes more complex, a progressive impairment of proficiency sets in.
(3) Insofar as the one test run of the Group Assembly Task may be indicative of performance on a group-participative task, relatively gross amounts of impairment appear.

ENVIRONMENT: UNDERWATER

AUTHORS: Davis, F. M., Osborne, J. P., Baddeley, A. D., and Graham, I. M. F.

TITLE: Diver performance: nitrogen narcosis and anxiety.

CITATION: Aerospace Medicine, 1972, 43, 1079-1082.

In two experiments in British waters 16 divers were tested twice underwater, once at a depth of 3 meters and once at 30 meters. They performed 4 tasks-a sentence comprehension test, a memory test, a simple arithmetic test and a manual dexterity test. All but the memory test show a significant drop in efficiency at depth: in Experiment 1; manual dexterity 22%, sentence comprehension 16% and arithmetic errors from 6% at 3 meters to 14% at 30 meters; in Experiment 2; manual dexterity 18% sentence comprehension 10% and arithmetic errors from 5% at 3 meters to 12% at 30 meters. In all three tests these changes are similar to those from boat-diving experiments in the Mediterranean, whereas manual dexterity impairment is greater than for equivalent shore diving in the Mediterranean. A tentative relationship between the extent of performance impairment of manual tasks at depth and anxiety in divers is suggested. (Author's abstract)

ENVIRONMENT: HYPERBARIC

AUTHORS: Frankenhaeuser, M., Graff-Lonnevig, U., and Hesser, C.M.

TITLE: Psychomotor performance in man as affected by high oxygen pressure (3 atmospheres).

CITATION: Acta Physiologica Scandinavica, 1960, 50, 1-7.

PURPOSE: This investigation attempts to determine the performance changes under high oxygen pressure using psychological criteria (i.e., performance on 3 psychomotor tasks).

METHODOLOGY:

SUBJECTS: Ten subjects (4 women and 6 men) aged 24-39 years participated. Four subjects were professional divers, the other six were laboratory technicians and medical students, two of whom were amateur divers.

EQUIPMENT: Apparatus included a visual choice reaction time device with red, green, and yellow lights mounted in the shape of a triangle. Two Morse keys were used as response buttons. On the mirror tracing task, a stylus and a metal plate in the shape of a star with sawtooth notches along the margin were used. A large recompression chamber was used equipped with a respiratory system which could deliver either oxygen or compressed air.

PROCEDURE: The experiment was conducted during 3 sessions. The first session was for indoctrination with the subjects practicing the psychomotor tasks at 1 ATA and 3 ATA while breathing air. In the second and third sessions the subjects performed the tasks while breathing oxygen at 3 ATA and air at normal atmospheric pressure (control condition). The tasks performed during each session were 1 minute on choice reaction time, 4 trials on mirror drawing, and 1 minute of simple reaction time. This series was followed by two similar series.

The psychomotor tasks included visual choice reaction time. Red, green, and yellow light signals were used. The subjects responded by pressing one of two Morse keys according to the following scheme: red light -- left hand key, green light -- right hand key, red and yellow lights simultaneously -- right hand key, green and yellow lights simultaneously -- left hand key. This was thus a 4-choice task involving reversals of response in addition to the basic 2-choice task. Twenty stimuli were presented in one minute. Four scores were recorded: a total score (the mean of 60 reaction times) and three subtotal scores, each of which was the mean of the 20 reaction times recorded during one 1-minute period. The visual simple

reaction time task followed the same procedure except that only one stimulus light and key were used. In the mirror drawing task, the subject was to move a stylus along a slit (visible only in a mirror) cut out in a metal plate so as to form a 5-pointed star. The slit had sawtooth notches along the margins to catch the stylus and so make the task more difficult. The time to complete one run was recorded as well as the time of contact between the stylus and the margins. Subscores for both completion time and error time were based on the 4 runs in each series and total scores were based upon 3 series of runs.

RESULTS: Results indicated that there were no appreciable differences in performance between the 2 groups on any of the psychomotor tasks.

CONCLUSIONS/RECOMMENDATIONS: The authors came to the following conclusions:

(1) The psychomotor tests used were sensitive enough to indicate any changes in performance during the pre-convulsive period of subjects on 3 ATA oxygen. Also, the time of exposure and pressure level were adequate to make the results valid.

(2) No significant impairment in psychomotor performance develops during the pre-convulsive period of exposure to high oxygen pressure (3 ATA). It is inferred that during this period no major disturbances occur in the areas of the cerebral cortex which control psychomotor performance.

ENVIRONMENT: HYPERBARIC

AUTHOR: Fructus, X. and J. P. Charpy

TITLE: Foreign title (Psychometric study of two subjects during a simulated dive to 52.42 ATA).

CITATION: Bull. Medsubhyp., Oct. 1972, 7, 3-12.

Performance measures carried out during the Physalie V dive to 520 m. are described. Both sensory-motor tests and mental tests were given. The results are interpreted as follows: First, the High Pressure Nervous Syndrome (HPNS) was much less acute than that observed in earlier dives at 400 m.; this fact is attributed to the compression curve, which was effectively scheduled to postpone the appearance of the syndrome;(the compression schedule is not given). Second, the psychometric tests make it possible to evaluate the real importance of the HPNS manifestations. In the manual dexterity tests, the divers showed a 20 per cent diminution of performance at 350 m and 420 m respectively. However, increase in tremor at 450 m and 520 m respectively was not reflected in further decline. The effect of HPNS on motor coordination was the most apparent, but not necessarily the most important, effect. In the visual choice reaction time tests, performance was more affected than in manual dexterity tests; this suggests that sensory function is involved. Performance degradation in visual choice reaction time tests seem related to the lowering of vigilance indicated by the results of the odd-even test. The lowering of vigilance is always more pronounced in one subject than in the other, and may be a question of intellectual process. The difference of these results might be due to two factors: (1) the less intelligent subject will demonstrate more fragile intellectual processes; (2) the indigenous differences between subjects might result in a difference in motivation and attitude, as these subjects clearly indicated. Relationships, pointed out elsewhere in the literature, between the EEG anomalies and modification of performance must be confirmed and defined before it can be determined whether they would clarify this problem. More findings on a larger number of subjects will help clarify the significance of the degradation in mental performance that was observed in one of the subjects. (MFW/BSCP)

ENVIRONMENT: HYPERBARIC

AUTHOR: Hamilton, R. W., Jr.

TITLE: Comparative narcotic effects in performance tests of nitrous oxide and hyperbaric nitrogen.

CITATION: Federation Proceedings, 1973, 32, 682.

Abstract only. Entire item quoted: The anesthetic properties of nitrous oxide allow this gas to be used in light doses as a model for the study of the nitrogen narcosis encountered in diving. We evaluated this model on two subjects by determining dose-response curves. A 25-minute package of cognitive psychomotor and sensory tests was repeated while subjects breathed several normoxic (0.2 atm) mixtures by mask. Five nitrous oxide doses ranged from zero to 0.5 atm. Five nitrogen mixtures (in He) were all breathed at a total pressure of 13.1 atmospheres; doses were from zero to 12.9 atm. In most cases test scores conformed to the upper part of an S-shaped dose-response curve for both gases. Slopes were eye drawn along the steep part of each curve, and the slopes were compared. For psychomotor tests (e.g. tracking) nitrous oxide is about 40 times as potent as nitrogen, but for cognitive tests(e.g. arithmetic) it may be less, about 30 times. Brauer and Way (JAP 29:23, 1970) found a ratio of 25.3 for righting reflex in mice.

ENVIRONMENT: HYPERBARIC

AUTHORS: Kiessling, R. J. and Maag, C. H.

TITLE: Performance impairment as a function of nitrogen narcosis.

CITATION: *Journal of Applied Psychology*, 1962, 46, 91-95.

PURPOSE: The primary goals of this study were: (1) to determine whether performance decrement appears at a simulated depth of 100 feet, (2) to evaluate the relationship between the amount of decrement and the complexity of the task, (3) to investigate performance efficiency as a function of duration of exposure at a constant pressure.

METHODOLOGY:

SUBJECTS: Ten subjects were used in the experiment: two senior medical students and eight experienced divers including one medical officer.

EQUIPMENT: Apparatus included a choice reaction time panel, a modified Purdue Pegboard, and a Conceptual Reasoning Test (CRT) developed by Maag (1957). The CRT consisted of 32 small wooden blocks which embodied 5 dichotomous characteristics, i.e. large-small, tall-short, round-square, etc. Half of the blocks were similar in at least one characteristic. Eight blocks were similar in at least two characteristics. Four blocks were similar in at least three characteristics. Using any one of the dichotomous characteristics it is possible to classify the blocks in any of several different ways. It was the subject's task to determine the classification system used by the experimenter.

PROCEDURE: Subjects were trained on three tasks (Choice reaction time, Purdue Pegboard, and Conceptual Reasoning Test) until a constant level of performance was achieved. During the experiment each subject was tested individually in a large U. S. Navy high-pressure chamber. Each experimental session consisted of three phases: a measure of performance of all three tests at sea level pressure; three 12-minute sessions at a pressure equivalent to a depth of 100 feet of sea water, during which time equal periods were allocated to each of the tasks; and a final measure during a period of decompression at a 10-foot depth.

SIGNIFICANT RESULTS: Results can be summarized as follows:

(1) All subjects demonstrated a significant performance decrement ($p < .01$) between sea level pressure and 100 feet of pressure on all three tests.

(2) A return to approximately normal performance during the 10-foot decompression stop was demonstrated on the three tasks by all subjects.

(3) It was demonstrated that the degree of performance decrement is directly proportional to the complexity of the task and that these differences exceed chance probability at better than the .01 level.

(4) It was noted that performance remains impaired . . relatively constant after the initial decrement under pressure and then improves again during the period of decompression.

CONCLUSIONS/RECOMMENDATIONS: The authors concluded that performance decrement occurs at depths as shallow as 100 feet contrary to previous results which stated no narcotic effect of nitrogen on performance until the 200 foot depth. Due to results it was recommended that the relationship between task assignment and performance efficiency be given serious consideration even at moderately low levels of nitrogen partial pressure.

ENVIRONMENT: UNDERWATER

AUTHOR: Kowal, J. P.

TITLE: Cold and the diver.

CITATION: Sea Frontiers, 1970, 16, 42-47.

The author discusses the investigations carried on by Dr. Hugh M. Bowen, made in a flooded rock quarry in Rhode Island using a movable platform which tested divers at 65°F and 45°F. Touch sensitivity, gross manual dexterity and hand and eye coordination, mental and memory function, and group assembly capability were tested on dry land and at both water temperatures. The water effect, noticeable at 65°F consisted of simple motor impairment, due to instability, neutral buoyancy, water resistance and lowered sensory functions. The cold effect, which occurs at temperatures lower then 55°F in a normal wet suit during a 30-min. dive, consists of marked lessening of touch sensitivity, finger dexterity and grip strength, and impairment of mental and memory function. The more complex the task, the greater the deterioration. The degree of impairment varies greatly among individuals. An attempt will be made to determine what factors contribute to this variation. Provided the diver is protected against narcosis, cold is the single greatest deterrent to performance. Heated suits as they present exist relieve the cold stress but are so combersome that they greatly impair motor function. (MFW/BSCP)

ENVIRONMENT: HYPERBARIC

AUTHOR: Miasnikov, A. P., Iu. M. Bobrov, and V. S. Shchegolev

TITLE: Foreign title (Changes of psychophysiological qualities under conditions of elevated atmospheric pressure).

CITATION: Voennomed. Zh., May 1971, (5), 81-82.

Study of the effects of elevated atmospheric pressure on the capacity and stability of attention, short- and long-term memory, ability for estimating time, excitability and equilibrium of nervous processes in humans. Experiments conducted over a six-month period included two exposures to a pressure of 11 atm, three exposures to 9 atm, and periodic exposures to pressures ranging from 2.2 to 7 atm. Statistically significant reductions were observed in the capacity and stability of attention. The response time of a simple sensomotor reaction to light stimuli increased, and the accuracy of time estimates decreased. Word lengths in handwriting tests increased. Short- and long-term memory capacities were reduced at 11 atm. (TM) (IAA)

ENVIRONMENT: HYPERBARIC

AUTHOR: Moeller, G. and C. P. Chattin

TITLE: Identification of tasks sensitive to hyperbaria with determination of time interval effects on performance.

CITATION: U. S. Naval Submarine Medical Research Laboratory, Report NSMRL 762, 10 p., Sept. 14, 1973.

It was found that an adaptive tracking task proved sensitive to narcotic effects of 7 AT. air, two mental arithmetic tasks did not. With intervals of 5-20 days between exposures at 7 ATA, much larger decrements in tracking performance were found in the first exposur than in the second. Preceding, or intervening, exposures at 2 ATA did not moderate narcotic effects of the "deeper" exposure in any way. The findings suggest that: (1) susceptibility to narcosis during an hyperbaric exposure can be reduced substantially by an orientation exposure only if its profile closely resembles those working exposures to follow; and (2) studies of the depth-performance relationship must provide for measurement of the effect of sequence of exposures when subjects are tested at several depths. (Author's summary)

ENVIRONMENT: HYPERBARIC

AUTHOR: O'Reilly, J. P.

TITLE: Hana Kai II: A 17-day dry saturation dive at 18.6 ATA. VI. Cognitive performance, reaction time, and personality changes.

CITATION: Undersea Biomedical Research, Sept. 1977, 4, 297-305.

Measures of spatial orientation, associative memory, general intelligence, arithmetic ability, reaction time, and personal/social perceptions were administered to five subjects during a 31-day saturation exercise. Performance decrements were noted during 17 days of exposure to hyperbaric He-O_2 at 18.6 ATA. Significant losses in general intellectual ability were noted, as well as trends toward signif- icant losses in general intellectual ability were noted, as well as trends toward significant losses in other cognitive tests. Reaction time and arithmetic errors increased significantly during the early testing sessions. Performance during a 3-day cold period was equivocal; arithmetic errors increased, but other measures improved or remained constant. Environmental stressors such as fatigue, anxiety, health problems, personal and social adjustment, and aspects of perceptual deprivation were considered to be influential in reducing performance effectiveness. (Author'abstract)

ENVIRONMENT: HYPERBARIC

AUTHOR: Parker, J. W.

TITLE: Performance effects of increased ambient pressure. II. Helium-oxygen saturation and excursion dive to a simulated depth of 1100 feet.

CITATION: U. S. Naval Submarine Medical Center, Report SMRL 596, 15 p., Oct. 15, 1969.

Two experienced, commercial divers were administered a simple addition test, a letter cancellation test, a geometric forms test and a choice reaction-time test (RATER) at selected intervals before, during and after a simulated, helium-oxygen dive in a pressure chamber complex to a saturated depth of 800 feet equivalent with excursion dives to 1000, 1050 and 1100 feet. The compression rate was 3.5 feet per minute. Few, if any, significant decrements in performance on any of the measures were noted. In fact, in some instances, slight improvements were found which cannot be attributed to learning or practice effect. Most changes were postulated as being due to motivational factors. Future plans for validation of additional performance measures are presented. (Author's abstract).

ENVIRONMENT: HYPERBARIC

AUTHOR: Parker, J. W.

TITLE: The effects of saturation/excursion diving on human performance.

CITATION: In: Aerospace Medical Association. Preprints of scientific program, 1970. Annual scientific meeting, St. Louis, April 27-30, 1970, p. 46-67. Published by the Association.

This paper reports the effects of depth and breathing mixtures of performance in two simulated saturation/excursion dive experiments. The first was at saturation depth of 800 feet, with excursions to 1000, 1050 and 1100 feet using H_2O_2. The tests consisted of simple arithmetic problems, a cancellation test and a Response Analysis Tester (RATER), which is a choice-reaction time matching test. Little or no effect of narcosis or other impairment was indicated by the results of these tests. The second experiment consisted of five chamber dives conducted in preparation for Tektite I, at saturation depths of 45 and 55 feet with excursions to 100 feet, using a high-nitrogen breathing mixture. The same tests were used. A marked decrement in the RATER test was observed at 100 feet on one of the dives. Aside from this, performance decrements were not significant. The exceptional instance is still to be explained (MFW/BSCP)

ENVIRONMENT: HYPERBARIC

AUTHOR: Parker, J. W.

TITLE: Perceptual and motor effects of air at 2-9 ATA

CITATION: In: Abstracts of BuMed-ONR sponsored Navy-wide workshop in high pressure biomedical research, U. S. Submarine Base, Groton, Conn., May 1971, p. 32, Published by the Naval Submarine Medical Research Laboratory, 1971.

Abstract only. Entire item quoted: Eight subjects were exposed to hyperbaric conditions at 50, 100, 150, 200 and 250 feet of sea water in a man-rated chamber. Each subject made two dives to each depth in a random order. Subjects were tested with a single digit addition test, a cancellation test and the Response Analysis Tester (RATER), a choice reaction-time test in two modes, self-and auto-paced. Data also were collected on the surface before and after the series of chamber dives. Results with the addition test showed a decline in the number of problems attempted and a decrease in accuracy as pressure increased. Cancellation accuracy also was affected by increased depth. RATER scores showed a decrease with increased pressure especially in the self-paced mode. Auto-paced scores as well as number of errors of omission and commission did not demonstrate as great an effect. Noteworthy is the fact that great variability among subjects was found. Pre-and post-experimental surface data covered a relatively

ENVIRONMENT: HYPERBARIC

AUTHORS: Poulton, E. C., Catton, M. J., and Carpenter, A.

TITLE: Efficiency at sorting cards in compressed air.

CITATION: British Journal of Industrial Medicine, 1964, 21, 242-245.

PURPOSE: This study examined the effect of compressed air on men sorting playing cards, in order to resolve conflicting results from previous studies.

METHODOLOGY:

SUBJECTS: Thirty-four men divided into four groups served as subjects. They consisted mainly of engineers and technical tradesmen working on a power station project and ranged in age from 19 to 52 years. An additional group of six students from Cambridge University, aged 17 to 24 years, was used as a control group.

EQUIPMENT: A Himalayan Card Sorter was used to test the subjects. It consisted of a wooden box with four rectangular holes in the top through which regular playing cards could be inserted according to suit. A card passing through each opening tripped a photoelectric switch which registered on a magnetic tape.

PROCEDURE: Four groups of subjects were tested under pressure in the medical lock at the construction site. Pressures used were 3½ atmospheres absolute (ATA), 2½ ATA, and 2 ATA. A control group was tested later at normal atmospheric pressure under comparable conditions at a Cambridge laboratory. All experimental subjects were first pressurized to 3½ ATA for 10 minutes before the appropriate pressure was set so as to reduce the amount of time needed for them to feel the full effects of the pressure. Before the first test, subjects practiced the task for 2 minutes. The subject started the test with a deck of cards held face down in his hands. He was told to sort the cards into suits as quickly as possible for 10 minutes without making errors. If the subject reached the end of the deck he took another one from a bench next to him and continued to sort. A second test was administered to all subjects at normal pressure.

SIGNIFICANT RESULTS: Three dependent measures were used to evaluate performance: the mean number of seconds per card, the mean standard deviation in seconds, and the mean percentage of very slow responses (i.e. responses greater than or equal to 2.5 seconds). The latter proved to be the most sensitive measure of performance.
Results were as follows:

(1) The group sorting cards at $3\frac{1}{2}$ ATA took a longer time per card than did the group at normal pressure ($p < .05$).
(2) Using mean variability in timing as a performance criterion, Group B ($2\frac{1}{2}$ ATA) was also significantly worse than the normal pressure group.
(3) Using mean percentage of slow responses as a criterion, the group at 2 ATA was reliably worse than the control group.
(4) Finally, in the second test in which the control group sorted cards at $3\frac{1}{2}$ ATA, performance did not differ from the other groups at normal pressure.

CONCLUSIONS/RECOMMENDATIONS: The authors come to the following conclusions:

(1) Pressure as low as 2 ATA affects card sorting performance. Thus, it can not be assumed that tasks requiring complex mental operations after prolonged exposure to 2 ATA or greater will be performed as well as at normal atmospheric pressure.
(2) At the relatively low pressures used, performance was affected only when men were performing the task for the first time and it was unfamiliar and relatively difficult. Once the task had been well-practiced, it was not affected even by a pressure of $3\frac{1}{2}$ ATA.

ENVIRONMENT: UNDERWATER

AUTHOR: Reilly, R. E. and B. J. Cameron

TITLE: An integrated measurement system for the study of human performance in the underwater environment.

CITATION: Contract N00014-67-C-0410. Arlington, Va., Biotechnology, Inc., Dec. 1968, 100 p.,(AD 680 028).

The report describes a system to measure human mental and perceptual-motor functions at ambient pressures of up to 444 lb/in squared, equivalent to a depth of 1000 feet. Designed for use in the environmental chambers at the Navy Experimental Diving Unit, the subject's equipment will operate in wet or dry surroundings. The system permits remote administration and scoring of 26 specific tests ranging from simple reaction time to complex manual tracking, and from monitoring a simple display to solving difficult mental arithmetic and symbolic problems. As a formal test battery and general research tool, the system is expected to have extensive application in the areas of (1) specification of human underwater performance capabilities, (2) delineation of factors of the diving environment which affect performance, and (3) development of diver selection criteria. (Author) (USGRDR)

ENVIRONMENT: HYPERBARIC

AUTHOR: Schreiner, H. R., R. W. Hamilton, A. D. Noble, L. A. Trovato, and J. B. MacInnis

TITLE: Effects of helium and neon breathing on man at 20.7 atm pressure.

CITATION: Federation Proceedings, Jan.-Apr. 1966, 25, 230.

Abstract only. Entire item quoted: Narcotic effects on man of Xe at a partial pressure of 0.8 atm, and of Kr, Ar and N_2 at higher pressures are well known. The question of whether He and Ne would exhibit narcotic effects at pressures associated with dives to continental shelf depth has remained unresolved. The present study was conducted to make a quantitative assessment of this possibility. Two trained diving subjects were exposed for 24 hours to a mixture of 1.7% O_2 and 98.3% He at a pressure of 20.7 atm. At the end of this equilibration period both subjects breathed a He-O_2 mixture from a semi-closed circuit apparatus. Psychomotor skill and mental acuity was measured during this period, and again during a subsequent 30 minute period when the He in the subject's breathing mixture was replaced by Ne. Neither He nor Ne possess measurable narcotic potency at partial pressures of 19.0 and 16.3 atm respectively. Biochemical and physiological studies on both subjects revealed no adverse changes as a result of the experimental exposure.

ENVIRONMENT: UNDERWATER

AUTHORS: Stange, P. R. and E. L. Wiener

TITLE: Diver performance in cold water.

CITATION: Human Factors, 1970, 12, 391-399.

PURPOSE: This investigation attempted to fill in the gap in the lack of quantitative data available on the effect of cold water on a diver's working performance.

METHODOLOGY:

SUBJECTS: Subjects consisted of 12 male divers ranging in age from 21 to 28 years and with 2 to 11 years SCUBA experience.

EQUIPMENT: All subjects wore swimming trunks and full 3/16 inch thick neoprene wet suits. The experiment was carried out in a plywood and fiberglass tank 8 feet high and 5 feet square. Tasks were performed on a specially constructed 24-inch high workbench frame rigidly attached to the tank. Equipment for performance measurement included a Mackworth "V" test, choice reaction time task, baseplate assembly task, torque bolt-task, speed-wrench task, a screwplate assembly task, screwplate task and taped mental arithmetic problems.

PROCEDURE: All subjects were run under all experimental conditions. Divers entered the tank at the same time on five consecutive days. On the first two days personal data was recorded, task orientation given, and the divers practiced the tasks at 60° F. During the next three sessions, the divers performed the tasks at 50°, 60°, and 70° F. During each 90-minute session the divers performed the complete set of 7 tasks six times. The tasks included:

1. Assemble Base Plate which involved simple assembly, i.e., attaching a plate to the work bench frame with wing nuts.
2. Torque Bolt, which involved full arm motion. The subject loosened torqued nuts and bolts with a wrench.
3. Speed Wrench which also involved full arm motion. The subject removed bolts with a speed wrench.
4. Assemble Screw Plate which required simple assembly. Subjects attached two plates together, one of which was first secured to the work bench with wing nuts.
5. Screw Plate which required fine digital motion. The subject transferred small nuts and screws from one side of a plate to the other.

6. Choice Reaction Time - Mental Arithmetic. A two-choice reaction time task was used as a primary task with mental arithmetic as a "loading task." The mental arithmetic task involved adding and subtracting integers.
7. "V" Test. This two-point tactile discrimination test was used as a measure of finger numbness.

SIGNIFICANT RESULTS: All primary tasks, with the exception of the Mental Arithmetic, showed a significant decrement with the lower temperatures. The screwplate task, requiring the greatest degree of manual dexterity, showed the greatest decrement, i.e., 40.7% for the 60° F to 50° F drop.

CONCLUSIONS/RECOMMENDATIONS: The authors conclude that in waters below 60° F, for times approaching 90 minutes, divers will show large decrements in performance. In 50° F water, grosser movements are less affected than finer movements, and simple assembly employing both gross and fine movements are only moderately affected.

ENVIRONMENT: UNDERWATER

AUTHOR: Streimer, I.

TITLE: Human performance characteristics in a complex manua
task underwater.

CITATION: Human Factors, 1972, 14, 95-99.

Five subjects executed a complex maintenance task at a pool depth of 6 ft. Heart rate, oxygen uptake, and task accomplishment times were continuously monitored. The results indicate that significant performance degradations may be anticipated during the performance of manual work under water.

ENVIRONMENT: UNDERWATER

AUTHOR: Streimer, I., D. P. W. Turner, P. Pryor, and K. Volkmer

TITLE: Experimental study of diver performance in manual and mental tasks at 66 feet.

CITATION: San Diego, Cal., Man Factors, Inc., Report MFI-71-115, 69 p., Sept. 1971, (AD 737,376).

Certain human performance characteristics developed during the execution of relatively complex work at a depth of 66 feet were studied. The tasks examined were: (1) A complex maintenance task involving the disassembly and reassembly of a water filtration unit. (2) A mental task involving the processes of numerical reasoning, digit memory span and pattern perception. The principal findings may be summarized as follows: (1) Irrespective of the task nature, energy expenditure rates during manual work remain remarkably constant. (2) Differences in task nature or difficulty are manifested by changes in productivity while energy expenditure rates remain constant. (3) Breathing gas consumption rates vary as a function of depth. (4) The percentage of oxygen removed from the available oxygen varies as a function of the energy investment level. (Author) (GRA)

ENVIRONMENT: UNDERWATER

AUTHOR: Vaughan, W. S., Jr.

TITLE: Distraction effect of cold water on performance of higher-order tasks.

CITATION: Undersea Biomedical Research, June 1977, 4, 103-116.

Eight U.S. Navy-qualified scuba divers performed peripheral target detection and navigation problem-solving tasks continuously during 3-h exposures to moderate (15.5°C) and cold (4.5°C) water. Upon exiting the water, the divers did a series of arithmetic computations. Measures of physiological cold stress were periodically recorded, and estimates of changes in body heat content were calculated. Results suggest a significant distraction effect of cold water exposure on performance of higher-order tasks. Hour-to-hour comparisons of task performance between the two exposures showed no significant differences except for the in-water tasks during the first hour of exposure. Furthermore, individual performance levels achieved during second and third hours of cold water exposure were significantly correlated with levels achieved in moderate water and not with individual differences in body cooling. It is recommended that the psychologically mediated effects of cold exposure be given greater attention in both research and operations. (Author's abstract)

ENVIRONMENT: UNDERWATER

AUTHORS: Vaughan, W. S., Jr., and Mavor, A. S.

TITLE: Diver performance in controlling a wet submersible during four-hour exposures to cold water.

CITATION: Human Factors, 1972, 14, 173-180.

Six 4-hr., open-sea test trials were conducted with a wet submersible. The purpose of these trials was to assess the effects of long exposure to cold (16.5° C) water on man's ability to perform basic submersible control tasks. The subjects were experienced submersible pilots who had a minimum of 20 hours training prior to the experimental trials. Skin and rectal temperatures were continuously recorded from both the pilot and rider of the submersible. A continuous record of vehicle depth and water temperature was also obtained. The pilot's task was to maintain a prescribed depth while performing a sequence of course changes for a 4-hr. period of submergence. Depth error variance was correlated with pilot core and skin temperature changes over time, and although pilot core temperature fell as much as 1.83° C, no degradation in depth control performance was apparent.

ENVIRONMENT: UNDERWATER

AUTHORS: Weltman, G., Christianson, and Egstrom, G. H.

TITLE: Effects of environment and experience on underwater work performance.

CITATION: Human Factors, 1970, 12, 587-598.

Five experienced divers and 15 novice divers completed a complex underwater assembly task and sets of written problems in a water-filled tank and in the ocean. Performance measurements included subtask completion times, problem-solving accuracy, activity analysis, and basic physiological variables. Experienced divers showed essentially unchanged performance between tank and ocean. Novice divers performed slower than the experienced divers in the tank and showed a marked decrement in both assembly time and problem-solving accuracy in the ocean. The results suggest that diving experience improves underwater motor skills rather than work strategy, and that psychological stress was a significant factor even at shallow ocean depths for novices.

ENVIRONMENT: UNDERWATER

AUTHOR: Weltman, G., T. Crooks, and G. H. Egstrom

TITLE: Diver performance measurement for SEALAB III.

CITATION: In: Lythgoe, J. N. and E. A. Drew, eds. Underwater Association Report, 1969, p. 53-55. Guildford, England, Iliffe Science and Technology Publications, Ltd.

Performance measurements were made in shallow water on two teams of divers that were to have participated in the U.S. Navy SeaLab Project. Indirect methods of recording the performance of constructional tasks and a questionnaire to elicit the diver's own assessment were developed. [The task in "Divercon I" consisted of assembling the underwater shelter, thus testing a divers' capabilities in control and communication, in fine manipulation and endurance of heavy work loads, as well as in the rather complicated solving due to the developmental nature of the task]. Heart rate recording suggested that some of the tasks imposed a heavy work load on the divers. [It was also found that as the divers left the water, laden with 150 pounds of gear, heart rate mounted to 180 beats/minute; this probably resulted from the immediately previous lack of hydrostatic gradient in the water, and may be considered a danger point in the dive]. (Authors' abstract expanded by MFW/BSCP)

ENVIRONMENT: HYPERBARIC

AUTHOR: None Listed

TITLE: 100 hours at 500 meters.

CITATION: CNEXO/COMEX Report, 8 p., Feb./Mar. 1972.

This is a preliminary report on the results of the simulated heliox dive carried out by COMEX in Marseilles February 21-March 6, 1972. A pre-dive of 6 days at 33 feet was made, during which environmental parameters were evaluated. Average temperature was 89°F, average humidity was 55, oxygen partial pressure was 4 atm during compression and saturation, and 5 atm during decompression. Compression to 1640 feet took 49 hours. The divers remained at this depth for 100 hours. Decompression took 141-1/2 hours. Complete physiological monitoring was carried out during the dive. The first symptoms of hpns appeared at 1000-1200 feet, and increased down to 1640 feet, becoming stabilized after the first 40 hours at 1640 feet. Constant polygraphic monitoring made it possible to complete the 100-hour bottom time. Symptoms were identical with those observed during the Physalie dives, i.e., static tremor, muscular jerks, lack of coordination, EEG changes, lessening of awareness. However, a fairly good persistance of motor, psychomotor and intellectual faculties was demonstrated by the satisfactory execution of psychomotor, and local static and dynamic effort tests. Muscular effort tests showed a sharp drop in stamina, associated with a noticeable respiratory limitation. Articular symptoms were greatly reduced by the

THE THERMAL ENVIRONMENT

PSYCHOMOTOR PERFORMANCE REVIEW

AND ANNOTATED BIBLIOGRAPHY

INTRODUCTION

Much research has been done on the effects of high environmental temperatures on psychomotor task performance. However, due to lack of methodological consistency among investigators, no definitive conclusions can be reached regarding which specific psychomotor factors are affected. With this point in mind, an integrative approach concerning the effects of heat on the following factors will be attempted: reaction time, vigilance, visual discrimination, spatial relations, manual dexterity, and fine control sensitivity.

Reaction Time

Generally, a hot environment (at dry/wet bulb temperatures ranging from $85^{o}/76^{o}$ to $145^{o}/117^{o}$) does not affect reaction time whether it be simple, choice, complex, or serial (Pace, 1945; Peacock, 1956; Mackworth, 1961; Bell, Provins, and Horn, 1964). Only one study found a small yet statistically significant effect from 90^{o} to 104^{o} F (Fraser and Jackson, 1955).

Vigilance Performance

Vigilance performance appears to be affected by high environmental temperatures (Fraser, 1957; Pepler, 1958; Mackworth, 1961; Bell, Provins, and Horn, 1964). Mackworth delineated 87.5^{o} F Effective Temperature (ET) as the point at which decrement began. Bell, Provins, and Horn (1964) analyzed their data with respect to their subjects' physiological state and found increased decrement with increased body temperature without mentioning the corresponding environmental temperature. Regarding vigilance, one can conclude only that a high ambient temperature (of possibly 87.5^{o} F ET and above) will cause a

performance decrement.

Tracking Performance

Performance on tracking and pursuitmeter tasks also deteriorates at high temperatures (Blockley and Lyman, 1951; Teichner and Wehrkamp, 1954; Pepler, 1959; Iampietro, Chiles, Higgins, and Gibbons, 1969; Griffiths and Boyce, 1971). The factors involved in these tasks are fine control sensitivity, arm-hand steadiness, and movement analysis. Since the temperatures explored by the above investigators ranged from 66° to 101° F ET, one can conclude that these three factors are affected by heat. The critical temperature at which performance decrement begins, however, is uncertain. Teichner and Wehrkamp (1954) found it to be any temperature above or below 75° F, while Griffiths and Boyce (1971) noted poorest performance at 75° F. Iampietro, Chiles, Higgins, and Gibbons (1969) found a decrement only at 101° F, and Blockley and Lyman (1951) and Pepler (1959) found no decrement until six to eight minutes before their subjects reached their physiological tolerance limits.

Fortunately, research on tracking and pursuitmeter tasks with weighted handles has yielded more consistent results. Generally, tracking performance is degraded (Carpenter, 1950; Pepler, 1958; Mackworth, 1961). Also, several investigators found the critical temperature for initial decrement to be approximately 87° F ET (Viteles and Smith, 1946; Teichner and Wehrkamp, 1954; Russell, 1957; Mackworth, 1961). It is likely that the three factors involved in the previous tracking and pursuitmeter tasks, (i.e. fine control sensitivity, arm-hand

steadiness, and movement analysis) are also salient for the same tasks with weighted handles. Therefore, one can tentatively conclude that tasks utilizing the above three factors will show a performance decrement beginning at about 87° F ET.

Miscellaneous Performance

Other tasks studied under high ambient temperatures involve such factors as visual discrimination, spatial relations, manual dexterity, and fine control sensitivity (Weiner and Hutchinson, 1945; Viteles and Smith, 1946; Mortagy, 1970). Based on the results of Weiner and Hutchinson (1945) and Viteles and Smith (1946), performance deterioration begins at either 91° or 87° F ET, respectively. Mortagy (1970) found a decrement at a much lower temperature (80° F) but the small number of subjects used (three) and the significant between subjects variance makes his value less credible.

Conclusions

From the studies presented above one can generally conclude that high environmental temperatures cause performance decrements on tasks involving such factors as vigilance, tracking, visual discrimination, spatial relations, manual dexterity, and fine control sensitivity. The only measure reviewed here which is generally unaffected by high temperatures is reaction time. Furthermore, those psychomotor factors which show a temperature effect generally do so at approximately 87° F ET (Viteles and Smith, 1946; Carpenter, 1950; Teichner and Wehrkamp, 1954; Russell, 1957; Mackworth, 1961).

Some inconsistencies may be noted, however. Those investigators who did not attain comparable results explained their

findings in terms of the subjects' physiological tolerance limits (Pepler, 1959; Blockley and Lyman, 1951). Other investigators did not convert their temperatures to the Effective Temperature scale, thereby making comparisons between studies difficult (Pepler, 1959; Bell, Provins, and Horn, 1964; Griffiths and Boyce, 1971). Some degree of consistency regarding the environmental temperature in relation to body temperature and length of time in the environment is needed before any definitive conclusions can be reached concerning the effect of high temperatures on psychomotor performance.

Table 4

Summary of Surveyed Articles

Reference	Environment	Factors Measured
Bell, C. R., Provins, K. A., and Horns, R. W. (1964)	Heat	Reaction Time, Aiming
Carpenter, (1950)	Heat	Manual Dexterity, Arm-Hand Steadiness, Fine Control Sensitivity, Movement Analysis
Chiles, W. D., Iampietro, P. F., and Higgins, E. A. (1972)	Heat	Manual Dexterity, Fine Control Sensitivity, Movement Analysis
Fraser, D. C., and Jackson, K. F. (1955)	Heat	Reaction Time
Griffiths, I. D., and Boyce, P. R. (1971)	Heat	Manual Dexterity, Fine Control Sensitivity, Movement Analysis
Iampietro, P. F., Chiles, W. D., Higgins, E. A. and Gibbons, H. L. (1969)	Heat	Manual Dexterity, Fine Control Sensitivity, Response Orientation, Rate Control, Spatial Relations, Movement Analysis
Leibowitz, H. W., Abernathy, C. N., Buskirk, E. R., Bar-Or, O., and Hennessy, R. T. (1972)	Heat	Reaction Time, Perceptual Speed, Time Sharing
Loeb, M. and Jeantheau, B. (1958)	Heat	Reaction Time, Manual Dexterity, Fine Control Sensitivity, Response Orientation, Spatial Relations, Perceptual Speed, Time Sharing

Table 4 (continued)

References	Environment	Factors Measured
Mackworth, N. H. (1946)	Heat	Undetermined
Mackworth, N. H. (1950)	Heat	Manual Dexterity, Arm-Hand Steadiness, Fine Control Sensitivity, Movement Analysis
Mackworth, N. H. (1961)	Heat	Reaction Time, Vigilance
Mackworth, N. H. (1961)	Heat	Manual Dexterity, Finger Dexterity, Arm-Hand Steadiness, Fine Control Sensitivity, Response Orientation, Spatial Relations, Movement Analysis
Mackworth, N. H. (1961)	Heat	Undetermined
Mortagy, A. K. (1970)	Heat	Response Integration, Spatial Relations
Pace, N. et. al. (1943, 1945)	Heat	Reaction Time
Peacock, L. J. (1956)	Heat	Reaction Time
Pepler R. D. (1958)	Heat	Manual Dexterity, Arm-Hand Steadiness, Fine Control Sensitivity, Movement Analysis
Pepler, R. D., (1959)	Heat	Manual Dexterity, Fine Control Sensitivity, Movement Analysis
Pepler, R. D., (1960)	Heat	Manual Dexterity, Fine Control Sensitivity, Movement Analysis

Table 4 (continued)

References	Environment	Factors Measured
Poulton, E. C. (1965)	Heat	Undetermined
Russell, R. W. (1957)	Heat	Manual Dexterity, Arm-Hand Steadiness, Fine Control Sensitivity, Movement Analysis
Teichner, W. H., and Wehrkamp, R. F. (1954)	Heat	Reaction Time, Fine Control Sensitivity, Rate Control
Weiner, J. S., and Hutchinson, J. C. D. (1945)	Heat	Fine Control Sensitivity
Viteles, H. S., and Smith, K. R. (1946)	Heat	Manual Dexterity, Finger Dexterity, Spatial Relations

Table 5

Summary of Articles by Factor Measured

Factor Measured	References
1. Reaction Time	Bell, Provins, and Horns (1964) Fraser and Jackson (1955) Leibowitz, Abernathy, Buskirk, Bar-Or, and Hennessy (1972) Loeb and Jeantheau (1958) Mackworth (1961) Pace, N. et. al. (1943,1945) Peacock (1956) Teichner and Wehrkamp (1954)
2. Manual Dexterity	Carpenter (1950) Chiles, Iampietro, and Higgins (1972) Griffiths and Boyce (1971) Iampietro, Chiles, Higgins, and Gibbons (1969) Loeb and Jeantheau (1958) Mackworth (1950) Mackworth (1961) Pepler (1958) Pepler (1959) Pepler (1960) Russell (1957) Viteles and Smith (1946)
3. Finger Dexterity	Mackworth (1961) Viteles and Smith (1946)
4. Multi-Limb Coordination	None Found
5. Arm-Hand Steadiness	Carpenter (1950) Mackworth (1950) Mackworth (1961) Pepler (1958) Russell (1957)
6. Fine Control Sensitivity	Carpenter (1950) Chiles, Iampietro, and Higgins (1972)

Table 5 (continued)

Factor Measured	References
	Griffiths and Boyce (1971) Iampietro, Chiles, Higgins, and Gibbons (1969) Loeb and Jeantheau (1958) Mackworth (1950) Mackworth (1961) Pepler (1958) Pepler (1959) Pepler (1960) Russell (1957) Teichner and Wehrkamp (1954) Weiner and Hutchinson (1945)
7. Response Orientation	Iampietro, Chiles, Higgins, and Gibbons (1969) Loeb and Jeantheau (1958) Mackworth (1961)
8. Speed of Arm Movement	None Found
9. Motor Kinesthesis	None Found
10. Response Integration	Mortagy (1970)
11. Spatial Relations	Iampietro, Chiles, Higgins, and Gibbons (1969) Loeb and Jeantheau (1958) Mackworth (1961) Mortagy (1970) Viteles and Smith (1946)
12. Wrist-Finger Speed	None Found
13. Position Estimation	None Found
14. Position Reproduction	None Found

Table 5 (continued)

Factor Measured		References
15.	Movement Analysis	Carpenter (1950) Chiles, Iampietro, and Higgins (1972) Griffiths and Boyce (1971) Iampietro, Chiles, Higgins, and Gibbons (1969) Mackworth (1950) Mackworth (1961) Pepler (1958) Pepler (1959) Pepler (1960) Russell (1957)
16.	Perceptual Speed	Leibowitz, Abernathy, Buskirk, Bar-Or, and Hennessy (1972) Loeb and Jeantheau (1958)
17.	Time Sharing	Leibowitz, Abernathy, Buskirk, Bar-Or, and Hennessy (1972)
18.	Mirror Tracing	None Found
19.	Aiming	None Found
20.	Vigilance	Mackworth (1961)

ENVIRONMENT: HEAT

AUTHORS: Bell, C. R., and Provins, K. A.

TITLE: Effects of high temperature environmental conditions on human performance.

CITATION: Journal of Occupational Medicine, 1962, 4, 202-211.

PURPOSE: This article reviewed literature on the effects of high environmental temperature on tasks which do not require great physical effort. Only those studies not reviewed elsewhere will be presented here.

METHODOLOGY: NA

SIGNIFICANT RESULTS:

Reaction Time

Pace (1943, 1945) found no increase in simple visual, auditory, two-choice, and complex-choice reaction times due to high temperatures.
Peacock (1956) found no temperature effect for a self-paced serial reaction time task.

Vigilance

Mackworth (1950) noted a decrement in a two hour visual vigilance test at 87.5° and 97°F ET. Fraser (1957) and Pepler (1958) obtained comparable results.

Tracking

Mackworth (1950) and Carpenter (1950) found performance decrements at 87°F ET for tracking tasks with weighted handles as did Teichner and Wehrkamp (1954) and Russell (1957).

Other

Blockley and Lyman (1950, 1951) and Pepler (1959) noted a facilitory performance effect during the first few minutes of exposure to high temperatures. It was suggested that this effect was due to pre-exposure anxiety.
Weiner and Hutchinson (1945) found that when a fine motor task was preceded by 20 minutes of physical exercise, performance degradation resulted.
Blockley and Lyman (1951) found no performance deterioration until five or six minutes before the subjects reached their physiological tolerance limits.

Pepler (1959) designed a study to replicate Blockley and Lyman's physiological conditions and the greatest decrement occurred eight minutes before the experiment's end. Peacock ((1956) found no decrement on a rifle-aiming steadiness test. It was suggested that the experimental trial was too short (less than one minute) for any effect to appear.
Bursill (1958) studied peripheral vision at 65^{o} and 95^{o}F ET and found that a subject's ability to detect objects in the periphery of his visual field decreased at the higher temperature.

CONCLUSIONS/RECOMMENDATIONS: Many problems exist in determining the effects of high environmental temperatures on psychomotor performance. Firstly, there is no agreement among investigators on methods of assessing performance effort or cost in an adverse environment. Also, the length of time spent in a hot climate is an important variable in determining performance. Sensory-motor performance degradation appears to be a result of reduced muscular and/or manipulative ability due to heat. Vigilance decrements, however, may be due to the subjects' subjective reports of "sluggishness and fatigue" as reported by Viteles and Smith (1946).

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ENVIRONMENT: HEAT

AUTHORS: Bell, C. R., Provins, K. A., and Horns, R. W.

TITLE: Visual and auditory vigilance during exposure to hot and humid conditions.

CITATION: Ergonomics, 1964, 7, 279-288.

PURPOSE: The purpose of this study was twofold: (a) to study the effect of environmental heat on visual and auditory vigilance and (b) to determine if there was any measurable relationship between vigilance performance and physiological reactions to climatic stress.

METHODOLOGY:

SUBJECTS: Eight volunteer naval subjects were used for both experiments.

EQUIPMENT: Broadbent's twenty-dials task was used in Experiment I. In Experiment II, two loudspeakers were mounted at equal distances from each subject to provide the auditory vigilance stimuli. In addition, 90 dB background noise was present in both experiments.

PROCEDURE:

Experiment I

The five environmental conditions were 85°/76°, 109°/95°, 124°/99°, 124°/109°, and 145°/117°F dry/wet bulb temperatures. Subjects were given two exposures to a particular climate on any one day. In the experimental session, subjects were told to watch the array of dials and to depress a foot pedal whenever on of the needles moved out of its safety zone. Reaction time was recorded. The experimental session duration was four hours unless subject physiological strain dictated early termination. Inter-signal intervals ranged from 40 seconds to 5 minutes, 20 seconds with the mean interval 2 minutes, 40 seconds.

Experiment II

The five environmental conditions were 99°/86°, 109°/95°, 122°/99°, 127°/104°, and 133°/109°F dry/wet bulb temperatures. Again, subjects received two exposures to a particular climate on any one day. In the experimental session the nature of the auditory vigilance task was explained and demonstrated. Reaction time was recorded by the subjects' pressing a button when a signal was detected.

SIGNIFICANT RESULTS: Experiment I

A median response time was calculated for each subject in each climate in each week. An analysis of variance showed no significant variance from either the between climates or the between weeks osurce. Between subjects variance was highly significant. An analysis of variance of missed signals revealed no significance between climates or between weeks. Again, between subjects variance was highly significant. The mean values of the subjects' median response times in the five conditions were 13.28, 12.90, 12.31, 12.18, and 12.04 seconds. The mean percentages signals missed were 11.2, 12.8, 9.4, 11.9, and 13.6 percent. A preliminary analysis of the subjects' oral temperatures during the initial 10 minutes of exposure revealed significant physiological inequivalence among the climatic conditions. Therefore, analyses of variance were conducted on median response times and percentages signals missed during this initial 10 minute exposure. Only inter-subject variance attained significance. The increase in median response time with increasoral temperature and the percentages signals missed was significant.

Experiment II

The proportion of signals missed to signals given was the performance criterion. An analysis of variance revealed significant variance only between climates.

CONCLUSIONS/RECOMMENDATIONS: It is possible that the 90 dB background noise provided a source of environmental stress. However, the subjects were familiar with this type and intensity of stimulation and rarely commented about it. Regarding the visual vigilance task, neither the analysis of median response time nor the analysis of percentages signals missed revealed any consistent effect with increasing climatic severity. However, the use of these two methods combined with a time analysis showed an effect with increased body temperature. Unfortunately, the auditory vigilance data did not lend itself to a comparable method of analysis. The absence of an effect in increasingly severe climates is disturbing unless one remembers that the subjects were all in a relatively average physiological state and then approached a physiological near collapse. If one therefore assumes a physiological basis for behavior, the same average vigilance performance in each climate would be expected. The authors concluded that the particular results in any given situation may depend on the type of test and the conditions of testing used.

ENVIRONMENT: HEAT

AUTHOR: Chiles, W. D.; Iampietro, P. F.; & Higgins, E. A.

TITLE: Combined effects of altitude and high temperature on complex performance.

CITATION: Human Factors, 1972, 14, 161-172.

Nine well-trained subjects were tested on a complex-performance device involving tracking, monitoring, and mental arithmetic during exposure to altitude (11,000 ft.) and heat (60° C) both singly and in combination. Several physiological measures were taken. Exposure durations were 30 min. for each condition with both pre- and posttesting. The only clear-cut effects of the conditions were significant differences across the environmental conditions on the tracking task. Altitude was clearly a more powerful variable than temperature in this study. This was evidenced by the fact that performance under the temperature-plus-altitude and the altitude-only conditions were approximately the same; performance under the temperature-only condition was significantly better than performance for either of the other two conditions. There was some evidence that the two environments in combination produced a persistent effect on performance that did not dissipate with return to normal conditions. Measured physiological functions of the subjects were within the tolerable range.

ENVIRONMENT: HEAT

AUTHORS: Fraser, D. C., and Jackson, K. F.

TITLE: Effect of heat stress on serial reaction time in man.

CITATION: Nature, 1955, 176, 976-977.

PURPOSE: This experiment was designed to determine the effect of ambient temperatures ranging from 90° to 104°F on serial reaction time.

METHODOLOGY:

SUBJECTS: Seven subjects were used.

EQUIPMENT: The apparatus used was a Cambridge visual vigilance test coupled to a photoelectric cell and a pulse-height discriminator operating a clock-starting relay.

PROCEDURE: The subjects were tested for five days, serial reaction time being measured before entrance into the heat chamber, after one hour of exposure to each of the above temperatures at 90-95 percent saturation, and after two hours exposure. For each measurement of reaction time the subject was presented with 40 stimuli in five minutes in random order.

SIGNIFICANT RESULTS: Data analysis of the mean serial reaction times revealed a small but statistically significant ($p < .01$) increase in reaction time due to high temperatures.

CONCLUSIONS/RECOMMENDATIONS: The authors concluded that serial reaction time offers a clear-cut index of psychomotor change under heat stress of this order.

ENVIRONMENT: HEAT

AUTHORS: Griffiths, I. D., and Boyce, P. R.

TITLE: Performance and thermal comfort.

CITATION: Ergonomics, 1971, 14, 457-468.

PURPOSE: The purpose of this study was to determine whether or not a sufficiently difficult psychomotor task combination would yield results consistent with comfort votes across a range of temperatures.

METHODOLOGY:

SUBJECTS: Fifty subjects between the ages of 20 and 40 years were used.

EQUIPMENT: A dot tracking device was used for the psychomotor task and a tape recorder and headphones provided the number sequences.

PROCEDURE: The experimental conditions were as follows: 60 degrees, 65 degrees, 70 degrees, 75 degrees, and 80 degrees F., relative humidity 50-60 per cent. Before entering the experimental chamber subjects received four five-minute dot-tracking practice trials at room temperature. Extensive training was also provided for the numbers task (matching of three numbers -- this will not be discussed in depth as it is not a psychomotor task, however, it did provide distraction from dot-tracking). After the training period subjects participated in four experimental trials which consisted of 100 sets of three digit numbers while dot-tracking. A five minute rest period separated experimental trials. Before and after the experimental sessions subjects completed questionnaires designed to assess their thermal comfort.

SIGNIFICANT RESULTS: Analyses were performed on both practice (single-task) and experimental (dual-task) data. The practice data did not show a significant temperature effect However, a very significant temperature effect was found on the dot-tracking task from the experimental session with performance being poorest at 75 degrees F. The comfort scales were scored and it was noted that performance under thermal stress and subjective evaluations of comfort coincide closely.

CONCLUSIONS/RECOMMENDATIONS: The fact that under thermal stress the dot-tracking task suffered in accuracy and the mental task did not led the authors to adopt an explanation of attentional selectivity. That is, under arousal conditions a subject will concentrate on the more difficult of two tasks at the expense of performance decrement in the other. The authors concluded that complex dual-task measures of performance increase the sensitivity of performance to thermal conditions.

ENVIRONMENT: HEAT

AUTHORS: Iampietro, P. F., Chiles, W. D., Higgins, E. A., and Gibbons, H. L.

TITLE: Complex performance during exposure to high temperature.

CITATION: Aerospace Medicine, 1969, 40, 1331-1335.

PURPOSE: The purpose of this study was to determine maximum time-temperature limits for adequate performance of aircrew in supersonic aircraft.

METHODOLOGY:

SUBJECTS: The subjects were 30 pilots between the ages of 30 and 51.

EQUIPMENT: A complex performance device was designed with the following functions: (a) an oscilloscope for two-dimensional tracking controlled by a stick, (b) three windows for presentation of two digit numbers (add first two, subtract third) and numbered buttons for presenting answer to experimenter, (c) meters to be monitored for deviations from null point with buttons to return needles to null point, and (d) lights to be monitored and turned off by buttons or keys.

PROCEDURE: Runs were made under three conditions--75°, 140°, and 160°F, relative humidity less than 10%. The day prior to the experimental session subjects received 90 minutes of training on the complex task device. For the experimental session, baseline data was recorded for 15 minutes at the control temperature of 75°F after which time chamber temperature was increased to the experimental condition over a period of 5-8 minutes. This temperature was maintained for 30 minutes, returned to 75°F over a 15 minute period and was maintained at such for 15 minutes to allow for the recording of recovery data. Three different workloads were performed for five minutes each: A=tracking, monitoring; B=tracking, monitoring, arithmetic; C=arithmetic.

SIGNIFICANT RESULTS: Decrements were not found on any of the tasks at either 75° or 140°F. Decrements were found on two measures under the 160°F condition. With task combination A neither measure revealed any effects of temperature. With task combination B absolute tracking error showed a significant decrement in the first subperiod (sixth through the tenth minute) but not in the second

subperiod (21^{st} through 25^{th} minute). The second measure that showed significant decrement was percent correct on arithmetic. However, this measure is irrelevant in that it is not representative of a psychomotor task.

CONCLUSIONS/RECOMMENDATIONS: The above temperatures were converted to effective temperatures (ET) where dry/wet bulb calculations for 75°, 140°, and 160°F were, respectively, 66°, 95°, and 101°F. The authors' concluding remarks dealt with the time sharing aspect of their study and related the above results to Wing's 1965 chart concerning effective temperature and mental performance (not psychomotor performance). As a result of this comparison it was noted that these subjects' performance decrement occurred sooner than what was indicated on Wing's chart. Suggested explanations for this was discomfort of handling hot metal objects and sweat in the eyes or on the hands at such high temperatures.

ENVIRONMENT: HEAT

AUTHORS: Leibowitz, H. W., Abernathy, C. N., Buskirk, E. R., Bar-Or, O., and Hennessy, R. T.

TITLE: The effect of heat stress on reaction time to centrally and peripherally presented stimuli.

CITATION: Human Factors, 1972, 14, 155-160.

PURPOSE: The purpose of this research was to investigate the performance of subjects exposed to heat stress and hypohydration resulting from extended work in a heat chamber.

METHODOLOGY:

SUBJECTS: The subjects were eight university students, four male and four female, half lean and half obese.

EQUIPMENT: An adjustable treadmill located in a heat chamber was used to obtain the desired weight loss. For the reaction time experiments, a set of eight amber lights were mounted at equal intervals on a circle with a red fixation light in the center at a height of 48 inches, 75 inches from the subject. The array of central lights subtended 1^{o} of arc with the individual lights subtending 12' of arc. The peripheral stimuli consisted of eight additional amber lights each subtending 1^{o} of arc at five feet. They were mounted on both sides of the fixation point at peripheral angles of 32^{o}, 45^{o}, 58^{o}, and 72^{o} The direction of the treadmill was in line with the central stimuli.

PROCEDURE: While on the treadmill, the subject was instructed to regard the fixation light and to indicate as quickly as possible (by means of a hand-held switch) whenever a central or peripheral light appeared. Reaction time measurements were made during the first and last five minutes of every other 20 minute walking period for a period of six hours. Two sessions were measured at the 2.5% and two at the 5% weight loss levels at one week intervals. After partial completion of the main experiment an additional maximum performance test was introduced at the end of each eight hour session. For the first of the 2.5 or 5% sessions body fluids were replaced during the two hour post exercise period, but in the other two sessions no fluids were replaced, thus imposing additional stress.

SIGNIFICANT RESULTS: The results were as follows:

(1) The effect of walks on mean peripheral reaction time was significant ($p < .01$).
(2) The central reaction time data remained relatively constant.
(3) The effect of dehydration, with or without fluid replacement, on peripheral reaction time was not significant.
(4) For the maximum performance test the peripheral reaction times were initially larger and decreased with time. The opposite effect was found for the central reactions.

CONCLUSIONS/RECOMMENDATIONS: The general conclusion that when peripheral and central stimuli are in competition performance on the peripheral task is initially poor but improves with practice is supported by the present study. Also, the above results do not indicate that the physiological stress resulting from high heat and hypohydration adversely affects either central or peripheral reaction times. However, this finding must be viewed in light of the conditions of this study, i.e., the subjects were highly motivated and the reaction time tests were made during less than 50% of the total walking time on the treadmill. The subjects were so bored on the treadmill that they viewed the reaction time tests as a welcome change of pace.

ENVIRONMENT: HEAT

AUTHORS: Loeb, M., and Jeantheau, B.

TITLE: The influence of noxious environmental stimuli on vigilance.

CITATION: Journal of Applied Psychology, 1958, 42, 47-49.

PURPOSE: This study was designed to investigate the influence of combined noise and vibration, of combined heat, noise, and vibration, and of heat alone upon the performance of a simple monitoring task. Only the results from the heat condition alone are presented here.

METHODOLOGY:

SUBJECTS: Twelve subjects were recruited from the Army Medical Research Laboratory.

EQUIPMENT: The task used was similar to Broadbent's "Twenty Dials". The subject was seated in an Army troop carrier.

PROCEDURE: Each subject performed 49 trials in three hours and 45 minutes at 110°-125°F with relative humidity 4-24 percent. Control data was obtained at 65-75°F, relative humidity 4-24 percent. Response time in milliseconds was the dependent variable. For purpose of analysis the 49 trials were divided into seven blocks of seven trials each, each block representing 32 minutes, with the median response time representing the average performance for each block.

SIGNIFICANT RESULTS: No significant difference in median response time was found between the heat and control conditions. Also, no changes occurred as a function of time.

CONCLUSIONS/RECOMMENDATIONS: On the basis of their study the authors concluded that increased ambient temperature has no effect on response time or vigilance performance on a simple monitoring task.

COMMENTS: Since no practice trials were allowed the subjects, the absence of any performance effects due to heat stress may be attributed to the fact that learning may have been taking place throughout the experimental sessions.

ENVIRONMENT: HEAT

AUTHORS: Mackworth, N. H.

TITLE: Effects of heat on wireless operators' hearing and recording morse messages.

CITATION: British Journal of Industrial Medicine, 1946, 3, 143-158.

PURPOSE: The main purpose of this study was to determine if a hot and moist environment impaired morse operators' performance and, if so, how high the temperature must be in order for such an effect to be statistically significant.

METHODOLOGY:

SUBJECTS: The subjects were 11 male volunteers. All were acclimatized and experienced wireless operators.

EQUIPMENT: Wireless telegraphy sets and an acclimatization chamber were the only equipment used.

PROCEDURE: Subjects worked at wireless telegraphy (W.T.) reception in five different effective temperatures (ET): 79°, 83°, 87.5°, 92°, and 97°F. Group A experienced these temperatures one per day on five successive days, beginning with the lowest and progressing to the highest. Group B experienced the same temperatures but received the same temperature for two days in a row thereby receiving twice the number of experimental sessions as Group A. Nine messages were sent in a three hour per day test period. Each message consisted of 230 groups which required just over 16 minutes each to transmit at a speed of 22 words per minute. Three minutes elapsed between messages.

SIGNIFICANT RESULTS: At ET 87.5°F there was a statistically significant fall in accuracy compared with performance at ET 79° and 83°F. The subjects were then classified as to their levels of competency and data analysis revealed that the level of operating efficiency determined the extent of performance decrement at a given temperature. Further data analyses indicated the decrement effects were not accumulating serially from day to day. There was a steady increase in errors throughout the three hour session. Twice as many errors were made in the second hour and three or four times as many during the third. This effect was less marked for those operators of exceptional ability.

CONCLUSIONS/RECOMMENDATIONS: N/A

ENVIRONMENT: HEAT

AUTHORS: Mackworth, N. H.

TITLE: Effects of heat and high humidity on prolonged visual search as measured by the clock test.

CITATION: Selected Papers on Human Factors in the Design and Use of Control Systems, H. Wallace Sinaiko (Ed.), New York: Dover Publications, Inc., 1961.

PURPOSE: The purpose of this experiment was to determine whether performance on the Clock Test deteriorated during exposure to high temperatures and, if so, at what point such deterioration reached statistical significance.

METHODOLOGY:

SUBJECTS: The subjects were 89 men between the ages of 18 and 29.

EQUIPMENT: The apparati consisted of a Mackworth Clock in an acclimatization chamber.

PROCEDURE: Subjects were acclimatized to all temperatures for a period of two weeks. The four effective temperatures (ET) used in this study were 70^{o}, 79^{o}, 87.5^{o}, and 97^{o}F. Each subject received a two hour practice trial at room temperature before attending the two hour experimental session at an elevated temperature.

SIGNIFICANT RESULTS: The results are summarized below:

(1) Statistical tests showed 79^{o}F (ET) to be the optimum temperature for a low incidence of missed signals.
(2) Performance in terms of missed signals was worse in the second hour than in the first, particularly at 87.5^{o} and 97^{o}F (ET).
(3) Experienced subjects performed better at the higher temperatures than the non-experienced.
(4) There was no difference between the median response times at different temperatures.

CONCLUSIONS/RECOMMENDATIONS: It was concluded that vigilance performance starts to deteriorate rapidly after one hour at an ET of 87.5^{o}F.

ENVIRONMENT: HEAT

AUTHORS: Mackworth, N. H.

TITLE: Effects of heat and high humidity on pursuitmeter scores.

CITATION: Selected Papers on Human Factors in the Design and Use of Control Systems, H. Wallace Sinaiko (Ed.), New York: Dover Publications, Inc., 1961.

PURPOSE: This study was designed to explore the effects of a hot and humid atmosphere on the performance of a task requiring prolonged yet intermittent heavy physical effort plus accurate muscular control.

METHODOLOGY:

SUBJECTS: The subjects were 10 sailors between the ages of 21 and 30.

EQUIPMENT: A pursuitmeter with a 50 pound weight, a light-manual control task apparatus, and an acclimatization chamber were the equipment used.

PROCEDURE: Subjects were fully acclimatized by spending 2-4 hours in humid atmospheres of effective temperatures (ET) 87° to 97°F every day for one month. They received three minutes of practice on the heavy pursuitmeter five times a day for six days. The subjects were tested in two groups of five men each in all of five ET conditions: 79°, 83°, 87.5°, 92°, and 97°F. Each experimental session lasted three hours, the first half-hour of every hour being devoted to a light task in which the subjects controlled a manual pointer with a light finger control instead of the heavily weighted meter. The second half-hour of every hour was devoted to the heavy pursuitmeter task where the subjects worked for three minutes, rested three minutes, then began the cycle again. Percent errors were combined for all subjects at each temperature.

SIGNIFICANT RESULTS: The results are summarized below:

(1) When all pursuitmeter errors were combined the error rate rose with the higher room temperatures.
(2) When only the last hour of the sessions was analyzed the error rate rose more steeply than in condition (1) above.
(3) Deterioration bore a logarithmic relation to atmospheric temperature changes.
(4) Calculations from a theoretical curve indicated that the significantly critical temperature for initial performance deterioration was ET 87°F.

CONCLUSIONS/RECOMMENDATIONS: The critical point at which performance begins to deteriorate was found to be 87°F (ET). That is, a significant performance decrement existed between 87°F and 79°F. This latter temperature was used as the control due to conditions in different ship compartments when in tropical waters. The above experiment provided useful data for determining priorities when assigning air conditioning to varying areas of a ship.

ENVIRONMENT: HEAT

AUTHORS: Mackworth, N. H.

TITLE: The pull test.

CITATION: Selected Papers on Human Factors in the Design and Use of Control Systems, H. Wallace Sinaiko (Ed.), New York: Dover Publications, Inc., 1961.

PURPOSE: This study attempted to determine the amount of work output under different atmospheric temperatures and whether knowledge of results would have any effect on such output.

METHODOLOGY:

SUBJECTS: The subjects were 30 men.

EQUIPMENT: The pull test equipment consisted of a table with an elbow rest and a hand grip attached to a rope with a 15 pound weight on the end which the subject raised via a pulley.

PROCEDURE: The fully acclimatized subjects were divided into six groups of five men each. Each group performed the test under two incentive levels: elaborate knowledge of results and no knowledge of results. The six effective temperatures (ET) were 61°, 69°, 79°, 83°, 87.5°, and 92°F. The subjects were instructed to raise the weight from the floor in time with a metronome. They were to continue until they could no longer raise the weight a fraction of an inch. The dependent variable was length covered by a measuring tape determining the total distance covered by the weight.

SIGNIFICANT RESULTS: The results are summarized below:

(1) At the four lowest temperatures those subjects in the knowledge of results condition performed significantly better than those with no knowledge of results.

(2) No significant difference was obtained in performance between the two incentive groups at 87.5° and 92°F.

(3) The critical temperature for performance deterioration using 61°F as a baseline was found to be 83°F for both incentive levels.

(4) The critical temperature using 79°F as a baseline was found to be 87.5°F for both incentive levels.

CONCLUSIONS/RECOMMENDATIONS: The above results show that at optimum work temperatures knowledge of results can significantly increase work output. However, at higher temperatures such knowledge is ineffective. The critical temperature range at which performance begins to deteriorate was calculated as 83°F-87.5°F (ET). The difference among critical temperatures depends upon which work output/temperature condition is used as the baseline.

ENVIRONMENT: HEAT

AUTHORS: Mortagy, A. K.

TITLE: Psychomotor performance in hot environments.

CITATION: Department of Industrial Engineering, Texas Tech University, Spring Semester, 1970.

PURPOSE: The present experiment was designed to study psychomotor performance as a function of elevated ambient temperature.

METHODOLOGY:

SUBJECTS: The subjects were three male college students.

EQUIPMENT: The vertical performance console consisted of a window through which pointers (revolving on a disk) could be seen. A vertical line divided the window in half. Underneath the window were two rows of five lights each. The horizontal portion of the console consisted of an identical arrangement of 10 buttons (i.e., two rows of five buttons each). An environmental chamber and various recording instruments were also used.

PROCEDURE: Three levels of effective temperatures (ET) were used--70°, 80°, and 90°F. Relative humidity was 50%. Subjects received white noise via headphones throughout the experiment. Each subject was to watch the pointer approach the vertical line and, when it did so, to press the button which corresponded to the light which flashed at that time. The lights flashed continuously and randomly. A separate light flashed when a subject scored a hit. If the subject missed, he waited for the next response opportunity. The possible response rate was 30/second. Subjects were allowed 15 minutes of practice. The task lasted 90 minutes.

SIGNIFICANT RESULTS: The reuslts are summarized below:

(1) Number of attempts--The source variations of subjects and time intervals (15 minutes) were both significant at the $p < .01$ level.

(2) Number of hits--The source variations of subjects and temperatures were significant at the $p < .05$ and $p < .01$ levels, respectively.

(3) Percentage of correct responses--The source variations of subjects and temperatures were significant at the $p < .01$ level.

CONLCUSIONS/RECOMMENDATIONS: The significant differences between subjects was expected due to individualized criterion adoptions. Regarding the effects of temperature on performance, all three measures indicated optimum performance at 70°F ET, a sharp decline in performance at 80°F ET, and slight improvement at 90°F ET. This slight improvement at 90°F was unexpected but explained by further data analyses of two subjects' scores. For these two subjects a learning effect was in operation which caused their performance to improve slightly over time.

ENVIRONMENT: HEAT

AUTHORS: Pepler, R. D.

TITLE: Warmth and performance: an investigation in the tropics.

CITATION: Ergonomics, 1958, 2, 63-88.

PURPOSE: The following two experiments were designed to explore the effects of a warm-dry and warm-humid environment on skilled subjects' proficiency at a tracking task.

METHODOLOGY:

SUBJECTS: The subjects were 32 healthy young men all of whom were naturally acclimatized to high heat and humidity.

EQUIPMENT: Four pursuitmeters were used for the tracking task. Lag and lead errors were scored electrically.

PROCEDURE:

Experiment I

Sixteen subjects worked in four indoor climates with the following dry/wet bulb temperatures of 75°/65°, 85°/75°, 93°/83°, and 100°/90°F with an average air movement of 80 feet/minute. The effective temperatures of these climates were 66°, 76°, 84°, and 91°F. Each subject had eight 15 minute runs during each session, one run on each pursuitmeter with each of two different weights on the control handle. The loadings measured at the subject's hand were 8 and 24 pounds. A five minute rest was given between each run.

Experiment II

This task was performed in eight climates with four effective temperatures (ET) at either 80 or 20 percent relative humidity. The dry/wet bulb temperatures of each pair of climates were as follows: 79°/74° and 89°/64°, 85°/80° and 100°/70°, 90°/85° and 110°/75°, and 97°/92° and 120°/85°F. The ET for each pair was 72°, 79°, 84°, and 92°F. Sixteen three minute tracking runs were given, one on each pursuitmeter with each of four control handle loads of 8, 16, 24, and 32 pounds. Three minute rest periods were given after every run.

SIGNIFICANT RESULTS:

Experiment I

The results are as follows:

(1) Errors rose sharply between 76° and 84°F (ET) but were stable above and below these temperatures.

(2) At 84° as compared to 76°F (ET) the subjects were making errors in both directions and were slow to respond to target changes. However, at 91°, lag errors increased greatly beyond those at 84°F (ET) while lead errors decreased.

Experiment II

The results are as follows:

(1) Regarding the effective temperatures of the four pairs of climates and the difference in relative humidity within the pairs, it was found that only the difference in temperature had a significant effect ($p < .05$).

(2) Errors increased significantly in the dry climates between the effective temperatures of 79° and 84°F, but between 72° and 79°F for the moist ones. Thus, the critical temperature range over which the accuracy of alignment deteriorated was lower for the moist than for the dry climates.

(3) At both levels of relative humidity the effect of handle loadings remained similar but varied significantly ($p < .05$) over the four warmth levels. This interaction was due mainly to the performances with the 16 and 32 pound loads at an effective temperature of 92°F. At 84°F (ET) tracking accuracy was significantly worse with the 32 pound load than with the 16 pound load.

CONCLUSIONS/RECOMMENDATIONS: The results of these experiments on men who had been living in the tropics and were thus acclimatized naturally to a warm humid environment were very similar to experimental results on men who had been acclimatized in the laboratory. The performances of naturally acclimatized men deteriorated over the same temperature region as those of artificially acclimatized men, i.e., between climates with dry/wet bulb temperatures of 90°/80°F and 95°/85°F. There was some evidence that manual tracking deteriorated over a lower range of effective temperature when the climate was humid than when dry.

ENVIRONMENT: HEAT

AUTHORS: Pepler, R. D.

TITLE: Extreme warmth and sensory-motor co-ordination.

CITATION: Journal of Applied Physiology, 14, 1959, 383-386.

PEPLER, R. D. *Extreme warmth and sensorimotor coordination.* J. Appl. Physiol. 14(3): 383-386. 1959.—Six subjects were exposed for 30 minutes on three occasions at 48-hour intervals to a very warm, humid climate with a wet bulb temperature of 105°F (41°C). During the second and third exposures the subjects worked continuously to keep a pointer aligned with a target mark, as it moved erratically from side to side. Accuracy of alignment was normal at first, but deteriorated rapidly and progressively. Movement of the pointer was greater than usual right from the start and changed little thereafter. Rectal temperature rose steadily during the exposures. Failures to correct progressively greater misalignments of the pointer were thought to indicate a growing inattentiveness to the task and a general deterioration in the organization of performance.

ENVIRONMENT: HEAT

AUTHORS: Pepler, R. D.

TITLE: Warmth, glare, and a background of quiet speech: a comparison of their effects on performance.

CITATION: Ergonomics, 3, 1960, 68-73.

In two experiments the effects of a high air temperature on the accuracy and manner of manual tracking were compared with those of quiet speech and of glare.

In each experiment 12 subjects attempted to keep a pointer aligned with a moving target for 40 min in both a normal and a warm climate, with instructions to be as accurate as possible. During the middle 20 min of each period of work the subjects in one experiment faced the glare from a naked electric lamp, and those in the other had a quietly spoken narrative relayed to them.

All three conditions reduced accuracy of alignment, but warmth affected the manner of tracking differently from quiet speech and glare. With the two latter conditions movements of the pointer decreased in number, i.e. errors of alignment were corrected less frequently. At a high air temperature the number of movements of the pointer increased, i.e. corrections were more frequent than usual. It was concluded that glare and a background of speech interfered with perception but that warmth affected chiefly accuracy of movement.

ENVIRONMENT: HEAT

AUTHOR: Poulton, E. C.

TITLE: Initial stimulating effect of warmth upon perceptual efficiency.

CITATION: Aerospace Medicine, 1965, 36, 29-32.

ABSTRACT

Twelve men listened to letters for 20 min. and *simultaneously* monitored 5 dials arranged in a semicircle, once at 45 C (113°F) and once at 25°C (77°F) in a counterbalanced order. Absolute humidity was maintained at 10 mm. Hg. and air movement at 500 ft. per min., giving effective temperatures of 30° C (86°F) and 19°C (65°F) respectively. On the first day efficiency was maintained reliably better in the warm than in the cool on both tasks ($p = .025$). On the second day efficiency depended partly upon the temperature, and partly upon the level of efficiency of the previous day. Conclusion: On first entering, a warm environment may have a stimulating effect upon perceptual efficiency.

ENVIRONMENT: HEAT

AUTHORS: Teichner, W. H., and Wehrkamp, R. F.

TITLE: Visual-motor performance as a function of short duration ambient temperature.

CITATION: Journal of Experimental Psychology, 1954, 47,447-450.

PURPOSE: The purpose of this study was to determine if a single-task performance decrement would occur at temperatures below as well as above the comfort range.

METHODOLOGY:

SUBJECTS: The subjects were 30 Army enlisted men.

EQUIPMENT: The apparatus was a Koerth-type pursuit rotor with a pressureless stylus. An electric clock graduated in .01 seconds was used to measure time on target.

PROCEDURE: The subjects were randomly assigned to one of five temperature conditions: 50°, 55°, 70°,85°, and 100°F. The experimental session consisted of 15 20 second trials on the pursuit rotor with a 10 second intertrial interval. This was done once daily for five successive days. In the data analysis, the 15 trials were divided into three periods of five seconds each. Mean time was calculated for each block of trials.

SIGNIFICANT RESULTS: An analysis of variance revealed no differences between periods, periods x days, or periods x temperatures. Graphing temperature on the abscissa and seconds on target on the ordinate, inspection revealed that performance for any day was best at 70° and worst at 100°F. However, performance declined more sharply at 55°F than 85°, both values differing from the optimal 70°F by 15°.

CONCLUSIONS/RECOMMENDATIONS: The above data indicate that response strength declines as the environmental temperature deviates in any direction from the comfort range, 70°F. This is in agreement with Viteles and Smith (1946) in spite of the fact that the present subjects received no practice trials nor performed the task for a long period of time.

ENVIRONMENT: HEAT

AUTHORS: Viteles, H. S., and Smith, K. R.

TITLE: An experimental investigation of the effects of change in atmospheric conditions and noise upon performance.

CITATION: Heating, Piping, and Air Conditioning, 1946, 18, 107-112.

PURPOSE: The purpose of this study was to determine the effect of diverse atmospheric and noise conditions upon output, feelings, and physiological functions during the performance of tasks roughly analogous to operations carried on by personnel in the plotting and charting rooms of Naval vessels. Only the performance output will be reviewed.

METHODOLOGY:

SUBJECTS: Forty subjects were used between the ages of 18 and 21.

EQUIPMENT: A heat chamber was used to establish the atmospheric conditions with an electric fan providing the appropriate dB level. Various equipment used in the psychomotor tests is described below.

PROCEDURE: Four temperatures were used with dry/wet bulb readings of 80°F/65.5°F (effective temperature (ET) 73°F), 88°F/73.3°F (ET 80°F), 98°F/81.5°F (ET 87°F), and 108.5°F/90.3°F (ET 94°F). The noise levels were 72, 80 and 90 dB. Performance in all combinations of temperature and noise was studied. The seven experimental tasks were the Discrimiter, the Mental Multiplication Test, the Number Checking Test, the Lathe Test, the Typewriter Code Test, the Locations Test, and the Pursuit Test. These tests are briefly described below:

(1) Discrimeter Test--This task consisted of a disk with a small window through which one digit was visible. Below the disk were four keys, each corresponding to the subjects' fingers. The subject pressed the key of the finger which corresponded to the visible digit. The score was recorded as the number of correct responses made in 30 minutes.
(2) Mental Multiplication Test--self explanatory.
(3) Number Checking Test--This task involved inspecting pairs of number sequences and checking those pairs in which both numbers were identical.

(4) Lathe Test--Each subject traced a stylus in a horizontal plane around a circular pattern by turning two control handles. Tracing off the pattern counted as an error. Tracing one-sixth of the circle correctly constituted a correct response. Performance time was one hour.

(5) Typewriter Code Test--A modified typewriter with a shield between the roller and subject was used. Through this shield the subject could see one letter of a row of letters on a sheet of paper inserted in the typewriter. Ten different letters were used and were scrambled in long rows. For each letter an appropriate key of the 10 keys on the top row of the typewriter was pressed. These keys represented a coded response, one symbol for each letter. Performance time was one-half hour.

(6) Locations Test--On each page of this test were large squares containing letters arranged in definite positions in rows and columns. Around each of these squares were smaller squares in which dots were located in the same relative position as a certain letter in the larger square. Over each dot the subject wrote the appropriate corresponding letter. Performance time was one-half hour.

(7) Pursuit Test--On each page of this test were 10 intertwined mazes. Each maze was eye-traced and the starting number of a maze was recorded in the appropriate goal box.

The experiment consisted of 42 experimental sessions of 5½ hours, six days a week, for seven weeks. A practice period of two hour sessions on four consecutive days at all temperature (72 dB) was instituted.

<u>SIGNIFICANT RESULTS</u>: The effects of performance changes in ET atmospheric conditions are summarized as follows:

(1) Total output (without respect to errors)--Output was not adversely affected by a change from 73^{o} to 80^{o}F ET. Differences between output at 87^{o}F ET and the lower temperatures were significant at the $\underline{p} < .05$ level or below for all of the tasks.

(2) Accuracy--No significant differences in accuracy between temperatures were obtained for any of the tasks.

(3) Performance Variability--There was a tendency for greater fluctuation in the amount of work done in successive five minute periods at 87^{o}F ET than at 73^{o} and 80^{o}F ET, respectively. This effect was statistically significant only for the Number Checking and Discrimeter Tests.

CONCLUSIONS/RECOMMENDATIONS: On the basis of these findings it was concluded that for tasks of the type employed above, no adverse performance effects will be found with an ambient ET temperature increase from 73° to 80°F for work periods up to four hours in length. With an increase to 87°F ET indications of adverse effects upon quantity and variability of performance appear. It is thought that 87°F ET marks the beginning of a "danger zone" regarding psychomotor performance.

INTRODUCTION

Cold has been defined as any temperature below 72° F which is the average room temperature in the United States (Fox, 1967). The effects of cold on performance, although studied since the 1930's and before, are far from being fully understood or easily integrated. Unfortunately, no one general theory about the effects of cold explains the degradation of performance or its lack of effect on various tasks. Its effect appears to be task dependent, however, certain categories of performance (i.e. manual performance, reaction time performance, tracking performance, etc.) can be delineated and are discussed below.

Manual Performance

The largest share of the research on cold has been directed toward its effects on manual performance. In general, manual performance is degraded in the cold, the amount of decrement depending upon the temperature and the type of task. Most of the tasks used involved the factors of Manual Dexterity and Finger Dexterity.

Many investigators have found that tasks such as Knot-tying and Block-stringing involving manual dexterity and finger dexterity show a loss in performance as hand skin temperature (HST) drops below a critical level (Clark, 1961; Clark and Cohen, 1960; Gaydos, 1958; Gaydos and Dusek, 1958; Lockhart, 1966; Lockhart, 1968). This critical level hand skin temperature is generally agreed to be around 55° to 60° F by most investigators.

Several other factors affect manual and finger dexterity.

Clark and Cohen (1960) and Lockhart (1968) compared fast and slow cooling rates and found that performance decrements increased sizeably as the rate of cooling decreased. Clark and Jones (1962) noted that if one-day training on a manual task were conducted under cold conditions a significant reduction occurred in the performance decrement usually associated with cold exposure. Several investigators (Gaydos, 1958; Gaydos and Dusek, 1958; Lockhart, 1966; Kiess and Lockhart, 1970) have investigated the effects of localized hand cooling versus general body surface cooling and the various combinations of warm hands-cold body, cold hands-warm body, etc. In general, they have found that performance on complex manual tasks (i.e. Knot-tying and Block-stringing) is adversely affected by lowering the temperature of the hands, regardless of the body temperature. An exception to this generalization is noteworthy. Kiess and Lockhart (1970) and Lockhart (1966) have found that if the hands are kept warm and the body cooled to a Mean Weighted Skin Temperature (MWST) of 78° F or below performance decrements will occur in manual tasks requiring accurate placement or threading of objects (e.g. Block-packing and Block-stringing tasks). Duration of body exposure to cold may also have an effect on manual performance particularly in tasks involving steadiness-aiming components such as Block-stringing (Lockhart, 1968).

Other aspects of manual performance, such as Wrist-Finger Speed, Aiming, and Arm-Hand Steadiness, also appear to show decrements in performance in the cold (Gaydos, 1958; Gaydos and Dusek, 1958; Kiess and Lockhart, 1970; Lockhart, 1966, 1968;

and Lockhart and Kiess, 1971). The tests employed in these studies were Block-Stringing, Block-Packing, Purdue Pegboard Assembly, Steadiness-Aiming, and Two-Plate Tapping tests. Kiess and Lockhart (1970) conclude that tasks requiring accurate placement or threading of objects (e.g. Block-Stringing or Purdue Pegboard Assembly) appear to be sensitive to the lowering of MWST while tasks requiring skilled movement of the wrist and fingers (Knot-Tying) and gross arm and hand movements (Two-Plate Tapping) are relatively resistant to low levels of MWST.

<u>Reaction Time</u>

Results of reaction time studies in the cold present a somewhat confusing picture of performance. In general, it seems apparent that reaction time suffers a decrement in severe cold, however, at more moderate temperatures it is difficult to generalize. Williams and Kitching (1942) after exposing subjects to severe cold for up to an hour concluded that there was no direct association between visual reaction time and body temperature. Horvath and Freedman (1947) concur with these results. Conversely, Teichner (1958) found that at windspeeds up to five miles per hour, low ambient temperature had no effect on reaction time, at least down to -35° F and probably down to -50° F. At windspeeds of 10 mph or greater, it was concluded that low ambient temperatures produced a significant decrease in reaction time. Evidently, more research is needed in this area to clear up these conflicting results.

<u>Tracking Performance</u>

Tracking performance studies definitely indicate a

decrement at low ambient temperatures (Provins and Clarke, 1960). Using a Pursuit Rotor test Teichner and Wehrkamp (1954) and Teichner and Kobrick (1955) found evidence of performance decrements below about 21° C (68.8° F). At a lower temperature of 13° C (55.4° F) the decrement was increased. These results were corroborated by Russell (1957) who conducted a study using two measures of tracking proficiency, both of which showed increasing impairment of performance below temperatures of about 10° C (50° F). Payne (1959) had less conclusive results. He found a peak of proficiency on the U. S. A. F. School of Aviation Medicine Multidimensional Pursuit Test at 13° C (55.4° F) but appreciable performance degradation at the lowest temperature used (4.5° C--40.1° F). The former result may have been due (in part) to the method of treatment of the results (Provins and Clarke, 1960).

Critical Hand Skin Temperature

Fox (1967) cites a number of studies supporting a clear relationship between Hand Skin Temperature (HST) and performance. Not only does lowering HST reduce manual dexterity, but it also reduces tactile sensitivity. For these two effects critical HSTs have been delineated above which performance is relatively unaffected and below which a noticeable decrement occurs. The critical Hand Skin Temperature for tactile sensitivity appears to be approximately 8° C. It is somewhat higher (12 to 16° C) for manual dexterity.

Conclusions

Various authors have offered explanations for the degradation of performance in the cold (LeBlanc, 1956; Teichner, 1958;

Fox, 1967). In general, these explanations apply to specific factors or categories of psychomotor performance. LeBlanc (1956), in explaining cold impairment of manual performance, found results pointing to a combination of increased synovial fluid viscosity in the finger joints and increased viscosity and lowered metabolic rate in the extensors and flexors of the forearm. Other investigators (most notably Teichner, 1958) hypothesize cold-induced psychological stress which causes a distraction effect. The most plausible explanation for the effects of cold on psychomotor performance appears to be a combination of the theories already advanced.

Table 6

Summary of Surveyed Articles

Reference	Environment	Factors Measured
Clark, R. E. (1961)	Cold	Manual Dexterity, Finger Dexterity
Clark, R. E. and A. Cohen (1960)	Cold	Manual Dexterity, Finger Dexterity
Clark, R. E. and C. F. Flaherty (1963)	Cold	Manual Dexterity, Finger Dexterity
Clark, R. E. and C. E. Jones (1962)	Cold	Manual Dexterity, Finger Dexterity
Fox, W. F. (1967)	Cold	Review Article
Gaydos, H. F. (1958)	Cold	Manual Dexterity, Finger Dexterity, Aiming
Gaydos, H. F. and E. R. Dusek (1958)	Cold	Manual Dexterity, Finger Dexterity, Aiming
Kiess, H. O. and J. M. Lockhart (1970)	Cold	Manual Dexterity, Finger Dexterity, Wrist-Finger Speed, Aiming
LeBlanc, J. S. (1956)	Cold	Finger Dexterity
Lockhart, J. M. (1966)	Cold	Manual Dexterity, Finger Dexterity, Aiming
Lockhart, J. M. (1968)	Cold	Manual Dexterity, Finger Dexterity, Arm-Hand Steadiness, Wrist-Finger Speed, Aiming
Lockhart, J. M. and H. O. Kiess (1971)	Cold	Manual Dexterity, Finger Dexterity, Aiming
Payne, R. B. (1959)	Cold	Manual Dexterity, Fine Control Sensitivity, Response Orientation, Time-Sharing

Table 6 (continued)

Reference	Environment	Factors Measured
Provins, K. A. and R. S. J. Clarke (1960)	Cold	Review Article
Teichner, W. H. (1957)	Cold	Manual Dexterity
Teichner, W. H. (1958)	Cold	Reaction Time
Teichner, W. H. and J. L. Kobrick (1955)	Cold	Manual Dexterity, Response Orientation
Teichner, W. H. and R. F. Wehrkamp (1954)	Cold	Manual Dexterity, Response Orientation

Table 7

Summary of Articles by Factor Measured

Factor Measured	References
1. Reaction Time	Teichner (1958)
2. Manual Dexterity	Clark (1961) Clark and Cohen (1960) Clark and Flaherty (1963) Clark and Jones (1962) Gaydos (1958) Gaydos and Dusek (1958) Kiess and Lockhart (1970) Lockhart (1966) Lockhart (1968) Lockhart and Kiess (1971) Payne (1959) Teichner (1957) Teichner and Kobrick (1955) Teichner and Wehrkamp (1954)
3. Finger Dexterity	Clark (1961) Clark and Cohen (1960) Clark and Flaherty (1963) Clark and Jones (1962) Gaydos (1958) Gaydos and Dusek (1958) Kiess and Lockhart (1970) Le Blanc (1956) Lockhart (1966) Lockhart (1968) Lockhart and Kiess (1971)
4. Multi-Limb Coordination	None Found
5. Arm-Hand Steadiness	Lockhart (1968)
6. Fine Control Sensitivity	Payne (1959)
7. Response Orientation	Payne (1959) Teichner and Kobrick (1955) Teichner and Wehrkamp (1954)

Table 7 (continued)

Factor Measured	References
8. Speed of Arm Movement	None Found
9. Motor Kinesthesis	None Found
10. Response Integration	None Found
11. Spatial Relations	None Found
12. Wrist-Finger Speed	Kiess and Lockhart (1970) Lockhart (1968)
13. Position Estimation	None Found
14. Position Reproduction	None Found
15. Movement Analysis	None Found
16. Perceptual Speed	None Found
17. Time Sharing	Payne (1959)
18. Mirror Tracing	None Found
19. Aiming	Gaydos (1958) Gaydos and Dusek (1958) Kiess and Lockhart (1970) Lockhart (1966) Lockhart (1968) Lockhart and Kiess (1971)
20. Vigilance	None Found

ENVIRONMENT: COLD

AUTHOR: Clark, R. E.

TITLE: The limiting hand skin temperature for unaffected manual performance in the cold.

CITATION: Journal of Applied Psychology, 1961, 45, 193-194.

The hands of 12 enlisted men were cooled to 55°F. and 60°F. surface temperature on different experimental days. Performance times to complete a standard knot-tying task were obtained when subject's hands first reached the appropriate hand skin temperature, after 20 minutes' exposure, and after 60 minutes' exposure.

It was found that performance was severely hindered when hand skin temperature fell to 55°F., and that performance decrements at this skin temperature level were increasing exponential functions of duration of exposure becoming asymptotic after about 40 minutes exposure. In contrast, performance at 60°F. hand skin temperature remained unaffected throughout the exposure period.

ENVIRONMENT: COLD

AUTHORS: Clark, R. E. and Cohen, A.

TITLE: Manual performance as a function of rate of change in hand skin temperature.

CITATION: Journal of Applied Physiology, 1960, 15, 496-498.

CLARK, R. ERNEST AND ALEXANDER COHEN. *Manual performance as a function of rate of change in hand skin temperature.* J. Appl. Physiol. 15(3): 496-498. 1960.—Manual performance (knot tying) was studied as a function of fast and slow rates of cooling during cold exposure and during subsequent rewarming. It was found that performance decrements accompanying cold exposure were sizeably increased as the rate of cooling decreased. These increased decrements associated with slow cooling perseverated even after the hands had been rewarmed to precooling temperatures. In addition, the results indicated a direct relationship between rate of cooling and rate of rewarming.

ENVIRONMENT: COLD

AUTHORS: Clark, R. E. and Flaherty, C. F.

TITLE: Contralateral effects of thermal stimuli on manual performance capability.

CITATION: Journal of Applied Physiology, 1963, 18, 769-771.

The performance capability of one hand was studied as a function of its surface temperature and that of the contralateral hand. Three findings were determined to be statistically reliable for the subject sample tested: a) when the performing hand itself was cooled to a surface temperature of 40 F, performance decrements appeared which were independent of the temperature of the contralateral hand; b) when the performing hand was kept warm, cooling of the nonperforming hand resulted in an average reduction of 33 % in the time typically needed for the completion of the manual task; and c) the surface temperature of a hand not exposed to the cold was found to fall an average of 2 F below its normal level when the contralateral hand was cooled to surface temperatures of 55 F or lower.

ENVIRONMENT: COLD

AUTHORS: Clark, R. E. and Jones, C. E.

TITLE: Manual performance during cold exposure as a function of practice level and the thermal conditions of training.

CITATION: Journal of Applied Psychology, 1962, 46, 276-280.

3 groups of 10 Ss each were given varied thermal experience (warm or cold hands) during 3 weeks of training on a standard manual task. The results were as follows: (a) 1 day of cold-hand training significantly reduced the size of a manual decrement usually associated with cold exposure, but continued cold experience did not; (b) skill level on the task per se did not interact with the cold-induced performance decrements; and (c) the thermal conditions associated with performance on the task appeared to become part of the stimulus complex eliciting correct manual responses when these thermal conditions were maintained for a large number of trials, i.e., the Ss learned, not merely to perform on the task, but to perform with warm, or cold, hands specifically.

ENVIRONMENT: COLD

AUTHOR: Fox, W. F.

TITLE: Human performance in the cold.

CITATION: *Human Factors*, 1967, 9, 203-220.

PURPOSE: The present paper attempts to summarize the existing literature on the effects of cold on human performance and to organize the findings in a meaningful fashion.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: Since this article reviewed the results of a great many studies which would be cumbersome to list here, only salient studies not available (and thus not included elsewhere in this bibliography) will be discussed below.

Manual Performance

(1) McCleary (1953)--Performance on the Brush Assembly Breakdown task (BAB) declined in the cold as a positively accelerated function of temperature declines. Performance declined rapidly below 0° F.

(2) Miller, Gundfest, Alper, Korr, Feitelberg, and Klein (1944)--Subjects exposed to -40° C and tested on a well-learned task showed a decline in performance compared with performance at normal ambient temperatures of 20° to 23° C. Performance deteriorated as Hand Skin Temperature declined and recovered upon rewarming.

(3) Horvath and Freedman (1947)--Subjects exposed to -20° F temperature were tested on the Johnson Code Test (a measure of finger dexterity) and the disassembly of a gear assembly from an Army vehicle. It was concluded that performance decrement for both tests was due primarily to impairment of finger dexterity. Poor performing subjects were the most affected while best performers were the least affected by the cold.

(4) Springbett (1951)--Significant impairment of manual performance was observed under natural conditions whenever the temperature inside of the subject's mitten reached about 26° C.

(5) Bartlett and Gronow (1952)--Performance on four manual dexterity tasks declined with exposure to -10° C.

(6) Rohles (1953)--Typewriting performance showed a significant increase in number of errors at 30° F compared to performance at 70° F. In a second study,

performance declined on finger dexterity and two-hand coordination tasks as a function of duration of exposure. No significant change in performance on rotary pursuit was found. It should be noted that the results on this study were confounded by practice effects.

(7) Peacock (1956)--Cold was found to seriously affect rifle aiming steadiness in the standing position.

(8) Aiken (1956)--At 14° F both completion time and accuracy scores were significantly lowered for a disassembly-reassembly task involving gross muscular skills and fine kinesthetic adjustments.

(9) Dusek (1957b)--Performance in the cold declined systematically with ambient temperature on the O'Connor Finger Dexterity Test, Purdue Pegboard Test, and the Minnesota Rate of Manipulation Test. Performance was particularly degraded on the former two tests and this was taken as evidence that fine finger dexterity is especially sensitive to the effects of low temperature.

(10) Rubin (1957)--Subjects wearing gloves performed under four temperature levels and three durations on several manual dexterity tests. The wearing of gloves significantly affected performance for the worse, but no significant effects were attributable to temperature or duration. It should be noted that the results were confounded with practice effects.

(11) Dusek (1957a)--A definite decrement in performance was observed whenever Hand Skin Temperature fell below 60° F. When Hand Skin Temperature dropped below 50° F there was an even larger decline in performance and subjects reported pain. Finally, when Hand Skin Temperature fell below 40° F there was complete loss of tactual discrimination and the ability to make fine manipulation.

Tracking

(1) Blair and Gottschalk (1947)--Performance on a tracking task declined 19 per cent upon exposure to -25° C and dropped an additional 21 per cent with exposure to -41° C. Part of the effect may have been due to cooling from the bare metal control which the subject held.

(2) Russell (1955; 1957)--Two variations of a tracking task were used. In the first task a handle controlling a stylus was adjusted so that there was a one to one correspondence between the handle and stylus movement. Only slight pressure on the handle was required in the second task to affect the stylus. Performance was not affected by duration of exposure. However, it declined steeply on both types of tasks when ambient temperatures were below 10° C.

Reaction Time

(1) Williams and Kitching (1942)--Simple reaction time (both visual and auditory) was relatively unaffected at 0° F, but was lowered at -50° F. The authors observed that subjects with the highest pre-experimental level of performance were the least affected by the cold while those with poorer performance were most affected.

(2) Horvath and Freedman (1947)--Neither lowered ambient temperature (-20° F) nor duration of exposure had any significant effect on discriminative reaction time.

(3) Forlano (1948)--It was concluded that when adequate protection is afforded the hands and feet, neither simple nor choice reaction time is significantly affected by exposure to low ambient temperatures.

(4) Teichner (1954)--Temperatures in a range from -50° to 117° F have little or no effect on reaction time.

REFERENCES: The following citations are for the studies listed above should the reader desire more information from them such as procedures, etc.

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Peacock, L. J. A field study of rifle aiming steadiness and serial reaction performance as affected by thermal stress and activity. U. S. Army Medical Research Laboratory Report No. 23 1, 1956.

Rohles, F. H., Jr. Two studies on temperature and motor ability: 1. The effect of temperature on serial-discriminative responses. 2. The effect of time and temperature on motor ability. USAF Arctic Aeromedical Laboratory Project 22-0601-0002, Report No. 1, 1953.

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Russell, R. W. Effects of variations in ambient temperature on certain measures of tracking skill and sensory sensitivity. U. S. Army Medical Research Laboratory Report No. 300, 1957.

Springbett, B. M. The effects of exposure to cold on motor performance. Defense Research Board of Canada, 1951.

Teichner, W. H. Recent studies of simple reaction time. Psychological Bulletin, 1954, 51, 128-150.

Williams, C. C. and Kitching, J. A. The effects of cold on human performance: 1. Reaction time. National Research Council of Canada, 1942.

ENVIRONMENT: COLD

AUTHOR: Gaydos, H.F.

TITLE: Effect on complex manual performance of cooling the body while maintaining the hands at normal temperatures.

CITATION: Journal of Applied Physiology, 1958, 12, 373-376.

PURPOSE: The present study was performed in order to determine whether impairment of performance could be prevented by maintaining the hands at normal temperatures even though the rest of the body was cooled to subnormal levels.

METHODOLOGY:

SUBJECTS: Twelve enlisted men served as subjects.

EQUIPMENT: Apparatus included a controlled temperature room, an electronically heated hand box, a knot-tying task, and a block-stringing task.

PROCEDURE: Before performing the main task, subjects practiced both knot-tying and block-stringing tasks at normal room temperature for five successive days. The ambient temperature during the main test session was 45° F. for both control and experimental conditions. For the experimental condition, the temperature of the hand warming box was at 90°-100° F. which kept the subjects' hand temperature at or above 80° F. For the experimental condition (body cooled, hands warm), the knot-tying and block stringing tests were administered three times during the session: (1) when the subject first entered the room, (2) when the subject's mean weighted skin temperature (MWST) had dropped to between 81°-82° F., and (3) when the MWST had dropped to between 78°-79° F. For the control condition (body cooled and hands cooled), the two tests were administered (1) when the subject first entered the room, (2) when the fingertip temperature had dropped to between 60°-65° F., and (3) when the fingertips temperature had dropped to between 50°-55° F.

All subjects performed under both conditions in a counterbalanced order.

SIGNIFICANT RESULTS:

(1) Lowering the mean skin temperature of the body had no effect upon performance of either task as long as normal hand temperature was maintained.
(2) When hand temperature was lowered by exposing them to the same cold to which the body was exposed, task performance deteriorated to an extent which seemed dependent upon the degree of hand cooling.
(3) There was a non-significant decline in manual performance on both tasks as finger skin temperature dropped from a mean of about 75° F.

to 60°-65° F. When hand temperature dropped to 50°-55° F., the performance decrement was definitely significant ($p < .05$).

CONCLUSIONS/RECOMMENDATIONS: The present study corroborates the consequent conclusions that local hand temperature is the main factor in performance decrement by showing that cooling of the body (within limits) has no effect upon complex manual performance so long as the hands are kept warm.

ENVIRONMENT: COLD

AUTHORS: Gaydos, H.F., and Dusek, E.R.

TITLE: Effects of localized hand cooling versus total body cooling on manual performance.

CITATION: Journal of Applied Physiology, 1958, 12, 377-380.

PURPOSE: The present investigation was performed to dispel the ambiguity surrounding factors involved in the decrement in manual performance caused by cold exposure.

METHODOLOGY:

SUBJECTS: Sixteen enlisted men volunteered for the experiment.

EQUIPMENT: A controlled temperature hand-cooling box and a controlled temperature room were used. Knot-tying and block-stringing tasks were used to measure manual performance.

PROCEDURE: To control learning effects, all subjects practiced both tasks at normal room temperature for six days preceding the experiment. For the test sessions, the controlled temperature room was set at $+15^{\circ}$ F.; the hand-cooling box was set at $+5^{\circ}$ F. with the room outside the box at 70-80° F. Subjects performed once under each of the two conditions (cold hands-cold body, and cold hands-warm body) in a counterbalanced order. To eliminate an uncontrolled variable, subjects were unable to see what they were doing and had to rely entirely upon their sense of touch when performing the tasks inside of the hand box. Test sessions consisted of: (1) three trials on each task immediately after entering the controlled temperature room or placing the hands in the cooling box, (2) three trials when the skin temperature of the fifth finger of the left hand dropped to 65° F., and (3) three trials when the temperature dropped to 50° F.

SIGNIFICANT RESULTS:

(1) No significant differences were found between performances under the two experimental conditions.
(2) At a hand skin temperature of 65° F., performance decrements of 5% and 9% were noted for the knot-tying and block-stringing tasks, respectively.
(3) At a hand skin temperature of 50° F., performance decrements were 27% and 23% for knot-tying and block-stringing ($p < .01$).

CONCLUSIONS/RECOMMENDATIONS:

(1) The performance of the complex manual tasks employed in this study was adversely affected by lowering the temperature of the hands.

(2) The decrement of performance appears to have been a function of local hand and forearm temperature alone regardless of the thermal environment surrounding the rest of the body.
(3) On the basis of these data, it appears that provision must be made to maintain hand temperature at normal or near normal levels to insure optimum efficiency of manual performance.

ENVIRONMENT: COLD

AUTHORS: Kiess, H.O., and Lockhart, J.M.

TITLE: Effects of level and rate of body surface cooling on psychomotor performance.

CITATION: Journal of Applied Psychology, 1970, 54, 386-392.

PURPOSE: The purpose of this study was two fold: (1) to determine if a slow rate of lowering Mean Weighted Skin Temperature (MWST) would result in manual performance decrements at less extreme levels of MWST than would a fast rate, and (2) to determine the relationship between performance decrements and subjective ratings of discomfort, shivering, and judged performance decrement due to cooling.

METHODOLOGY:

SUBJECTS: The subjects were 24 volunteer enlisted men assigned to the Climatic Research Laboratory of the U.S. Army Natick Laboratories. They ranged in age from 20 to 25 years and had all had prior experience with cold exposure. Some subjects had had previous experience with the tasks used.

EQUIPMENT: Equipment included a controlled temperature chamber, a large hand warming box with a thermostatically controlled heating element, thermocouples and other apparatus to measure MWST, Hand Skin Temperature (HST), and Rectal Temperature (RT). Tasks used to measure psychomotor performance included knot-tying, Purdue Pegboard assembly, block-stringing, and two plate tapping.

PROCEDURE: Prior to testing, each subject had 3 or 5 days practice depending on his previous experience with the tasks. Four levels of ambient temperature and two rates of lowering MWST were employed to obtain the desired levels of MWST: 85°, 78°, 74°, and 70° F. The two rates of lowering MWST were designated slow and fast rates of cooling and were obtained during 90 or 15 minute exposure periods before each test session. During this period subjects wore Arctic mittens to maintain HST which was maintained at about 85° F in the hand warming box during actual testing. Each subject performed the series of tasks three times with each task being performed for 30 seconds. After testing, each subject filled out a questionnaire containing two sets of questions, one dealing with body and extremity comfort with respect to temperature and a second set dealing with shivering and difficulty in performing the tasks.

SIGNIFICANT RESULTS: The following results were obtained:

(1) On the block-stringing task, performance was relatively unaffected by the level of MWST in the fast-cooling condition. However, in the

slow-cooling condition, performance decreased with decreasing MWST to a MWST of 74°.

(2) Except for the control condition, Purdue Pegboard performance under slow-cooling was poorer than under fast cooling and there appeared to be a greater decrease in performance for slow cooling at lower MWST than for fast cooling, although the Rate x MWST interaction was not significant.

(3) Rate and level of cooling did not affect performance on the knot-tying and two plate tapping tasks.

(4) On the questionnaire, slow-cooling subjects were somewhat more uncomfortable at all levels except 70° F. where both groups were equally uncomfortable. Slow-cooling subjects reported more shivering and task interference than fast-cooling subjects.

CONCLUSIONS/RECOMMENDATIONS:

(1) Tasks requiring the accurate placement or threading of objects (such as block-stringing or Purdue pegboard) appear to be sensitive to lowering of MWST while tasks which require skilled movement of the wrist and fingers alone (knot-tying) and gross arm and hand movements (two plate tapping) are relatively resistant to low levels of MWST.

(2) Rate of cooling, as defined in the present study, appears to be effective only when relatively low levels of MWST are achieved over a long period on tasks requiring accurate placement or threading of objects.

ENVIRONMENT: COLD

AUTHOR: LeBlanc, J. S.

TITLE: Impairment of manual dexterity in the cold.

CITATION: Journal of Applied Physiology, 1956, 9, 62-64.

PURPOSE: The present study attempted to estimate the fact. involved in manual dexterity impairment observed in the cold.

METHODOLOGY:

SUBJECTS: Eight gunners from a Canadian army regiment were used as subjects.

EQUIPMENT: Apparatus included a water bath in which to cool the hand, arm, or finger; Test A designed by Hunter and Test B. Test A consisted of moving the index finger from one point to another, around a baffle, so as to produce a maximum flexion of the proximal interphalangeal joint (approximately 90^{o}). Test B was a simple tapping test involving a 15^{o} flexion of the joint.

PROCEDURE: All subjects practiced the two tasks before the experiment began. When the cooling period was over, Tests A and B were performed for 10 seconds each at 1 minute intervals for periods varying between 10 and 15 minutes. Room temperature was $67^{o} \pm 3^{o}$ F.

Experiment I

The arm, with the hand excluded, was cooled for 10 minutes in ice cold water. At the end of this period Tests A and B were performed for 8 minutes.

Experiment II

The hand was cooled for 10 minutes. Tests A and B were then administered.

Experiment III

Tests A and B were administered after cooling the finger for 5 minutes.

Experiment IV

This was similar to Experiment 1 except that the arm was cooled for a longer period and the hand was kept warm in water at 33^{o} C.

SIGNIFICANT RESULTS:

(1) Experiment I--A marked drop in dexterity, as measured by Tests A and B was noted. The drop was approximately 20 per cent in both tasks.

(2) Experiment II--There was a marked drop in performance on Test A, however, the decrease in Test B performance was not as great.

(3) Experiment III--A sharp drop in performance on Test A was contrasted by no significant change in performance on Test B.

(4) Experiment IV--A marked drop of approximately 50 per cent in performance was observed on both tests.

CONCLUSIONS/RECOMMENDATIONS:

The following conclusions were stated:

(1) The decrement in finger dexterity when the arm is cooled (excluding the hand), indicates that the increased viscosity of the synovial fluid is not the only factor involved in the decrement.

(2) The decrement when the arm alone is cooled is probably caused by some arm muscle impairment, since cooling the muscles would decrease blood flow and reduce metabolism.

(3) The cooling of the finger causes a decrease in dexterity due to increased synovial fluid viscosity in the joint. The more joint movement involved, the more the decrement.

ENVIRONMENT: COLD

AUTHOR: Lockhart, J.M.

TITLE: Effects of body and hand cooling on complex manual performance.

CITATION: *Journal of Applied Psychology*, 1966, *50*, 57-59.

PURPOSE: The purpose of this study was to compare the roles of Hand Skin Temperature (HST) and Body Surface Temperature (BST) in complex manual performance using a lower BST than used in previous investigations.

METHODOLOGY:

SUBJECTS: Twelve U.S. Army enlisted men served as subjects.

EQUIPMENT: Apparatus included a thermostatically controlled hand box (range - 30° F. to 140° F.), a temperature controlled chamber and three manual performance tasks.

PROCEDURE: Subjects were divided into four groups of three subjects with each group receiving all four experimental conditions. The experimental conditions were: (1) Control -- Mean Weighted Skin Temperature (MWST) of 90° F. and HST of 93° F., (2) Cold Body -- MWST of 69° F. and HST of 90.4° F., (3) Cold Hand -- MWST of 85.8° F. and HST of 45.7° F., and (4) Cold Hand-Body -- MWST of 68.5° F. and HST of 45.8° F. Before testing all subjects received 10 practice trials on each task for 5 days. The three manual performance tasks used were: (1) Knot-tying -- tying one overhand knot and bight on each of a number of strings hanging from a rotatable disk, (2) Block-stringing -- stringing small blocks with holes through each face onto a needle and string, and (3) Block-packing -- packing small blocks in rows along the floor of a box.

SIGNIFICANT RESULTS:

(1) Under the Cold Body condition, there were significant decrements on the block-stringing and block-packing tasks ($p < .05$).
(2) Significant performance decrements occurred in all three tasks under the Cold Hand condition ($p < .05$) and the Cold Hand-Body condition.

CONCLUSIONS/RECOMMENDATIONS:

(1) If the hands are kept warm and the body allowed to cool to a MWST of 69° F., performance decrements will occur in manual tasks requiring accurate placement or threading of objects.
(2) Cooling the body while maintaining normal HST does not affect performance of tasks involving only wrist-finger speed and dexterity.
(3) When the HST is significantly lowered, generally manual performance decrements appear.

ENVIRONMENT: COLD

AUTHOR: Lockhart, J. M.

TITLE: Extreme body cooling and ps homotor performance.

CITATION: Ergonomics, 1968, 11, 24 -260.

PURPOSE: The purpose of this series of experiments was to investigate the following parameters of the effect of body cooling on psychomotor performance: (1) level of body cooling, (2) components of psychomotor performance, (3) rate of body cooling, (4) duration of cold exposure, and (5) practice during cold exposure.

METHODOLOGY:

SUBJECTS: The 16 volunteers were U. S. Army enlisted men.

EQUIPMENT: Apparatus included a thermostatically-controlled hand box and a temperature-controlled chamber. Performance tests used were the knot-tying task, block-stringing task, block-packing task, as well as the Craik screw, steadiness aiming, Purdue pegboard assembly, and two-plate tapping tests.

PROCEDURE:

Experiment I

Sixteen subjects were tested in groups of four on the block-stringing and block-packing tasks under four different levels of body cooling (Mean Weighted Skin Temperatures of 66°, 70°, 74°, and 78° F). Prior to testing subjects practiced each task and were tested under normal ambient temperature (80° F).

Experiment II

Sixteen subjects were tested in two groups on the Craik screw, Purdue pegboard assembly, steadiness aiming, and two-plate tapping tests under two conditions (MWSTs of 70° F, and above 85° F).

Experiment III

Sixteen subjects were tested in four groups on the block-stringing, steadiness aiming, and Purdue pegboard assembly tests under four treatment conditions (MWSTs of 78° F and 70° F after 15 and 90 minutes of cold exposure). This experiment tested the effect of slow versus fast cooling on performance.

Experiment IV

Twelve subjects divided into three groups were tested on the block-stringing, block-packing, and knot-tying tasks under three treatment conditions (MWST of 70^{o} F with additional cold exposure of 0, 20, or 40 minutes). This experiment tested the effect of duration of exposure on performance.

Experiment V

Sixteen subjects were tested in two groups on the block-stringing and Purdue pegboard assembly tasks under body-cooling conditions (MWST of 70^{o} F) and under normal ambient temperature conditions. Subjects received 10 30-second trials a day on each task for five consecutive days to test the effect of practice on body-cooling-induced performance decrements.

SIGNIFICANT RESULTS:

Experiment I

Performance on block-stringing and block-packing decreased linearly with level of body cooling (MWST 78^{o} to 66^{o} F).

Experiment II

Body cooling affected only one of two measures of steadiness performance on the steadiness-aiming test and did not affect Craik screw, pegboard, and tapping performance. Results from this experiment were considered inconclusive.

Experiment III

Significant decrements in block-stringing and pegboard performance were found only under the 70^{o} F MWST (vs. 78^{o} F MWST) and 90-minute exposure period condition (slow rate of cooling). For steadiness performance, the level of body cooling above was found to induce a significant decrease in performance regardless of the rate of cooling.

Experiment IV

In this test of duration of exposure, the mean for the 0-minute exposure period was found to show significantly better performance than the means for the 20-minute and 40-minute exposure periods. In these latter two periods performance was not significantly different from one another. Performance on block-packing and knot-tying was not significantly different across the three treatment conditions.

Experiment V

Pegboard performance was found to improve as a function of practice across both days and trials. Block-stringing performance showed a practice effect under both normal and body-cooling conditions across days but only the control group showed continued improvement across trials.

CONCLUSIONS/RECOMMENDATIONS: The authors conclude:

(1) That decrements in psychomotor performance resulting from cold exposure cannot always be alleviated by maintaining normal Hand Skin Temperatures.
(2) Body cooling does affect psychomotor performance as measured by certain tasks under specific conditions.
(3) The effects of body-cooling rate and duration of exposure are of practical significance since slow body-cooling rates may raise the MWST at which decremented performance begins to occur.

ENVIRONMENT: COLD

AUTHORS: Lockhart, J. M. and Kiess, H. O.

TITLE: Auxiliary heating of the hands during cold exposure and manual performance.

CITATION: Human Factors, 1971, 13, 457-465.

PURPOSE: The purpose of this experiment was to determine the effectiveness of applying radiant heat to the hands in preventing impaired manual performance during cold exposure.

METHODOLOGY:

SUBJECTS: The subjects were 20 volunteer enlisted men assigned to the Climatic Research Laboratory of the U. S. Army Natick Laboratories. Subjects ranged in age from 20-25 years and had previous experience with cold exposure.

EQUIPMENT: Equipment used included a wind tunnel, a 5 x 5-foot table, 3 infared heaters, knot-tying task, block-stringing task, Purdue Pegboard assembly, Minnesota Rate of Manipulation placing, and screw tightening task. In addition, various other apparatus was used to record Mean Weighted Skin Temperature (MWST) and Hand Skin Temperature (HST).

PROCEDURE: Prior to the experiment, each subject received five days practice on each task at 70° F. During the experiment, each subject served at five ambient temperature conditions: a control condition at 60° F.; ambient temperatures of 20°, 0°, and -20° F. with auxiliary heat; and 0° F. ambient temperature without auxiliary heat (the cold-exposure condition). Presentation order was counterbalanced. Under all ambient temperature conditions, the subjects wore insulated arctic boots, summer underwear, field trousers with liner, wool shirt, field jacket with liner, pile cap, arctic parka with liner and arctic hood. Between testing periods, subjects wore arctic mittens except in the control condition.

Upon entering the chamber, each subject immediately performed three consecutive trials on each of the tasks (test period 1). After completing the tasks, the subjects rested until the next test period. The task series was replicated on test periods two, three, and four after 60, 120, and 180 minutes of exposure, respectively.

SIGNIFICANT RESULTS: Two analyses were performed. The first assessed the effects of auxiliary heat at ambient temperatures of 20°, 0°, and -20° F. compared to the 60° F.

control condition. The second analysis evaluated performance at 0^{o} F. with and without auxiliary heat. Results were as follows:

(1) With the exception of the screw-tightening task, no significant decrements in performance on the tasks were noted between the 60^{o} F. control condition and the 0^{o} F. condition with auxiliary heat. Screw-tightening performance was impaired at periods three and four during this condition.

(2) Mean knot-tying performance for the -20^{o} F. auxiliary heat condition was not significantly different from that for the control condition at each period. However, for the other tasks, the use of auxiliary heat did not prevent impaired performance as compared to the 60^{o} F. control condition.

(3) Performance decrements on all tasks at -20^{o} F were alleviated relative to those of the cold-exposure condition by the use of auxiliary heat.

(4) Correlation coefficients between the time scores for each task and the HST of the subjects revealed two patterns. Significant negative correlation coefficients reflected the occurrance of lowered skin temperature with long time scores and vice versa. The other pattern involved negative correlation between pegboard-assembly performance and hand skin temperature for the cold condition and the -20^{o} F. auxiliary heat condition. For the cold-exposure condition, performance correlated significantly with HST at the back of the hand for each of four periods and with HST at the little and middle fingers for periods one and two. When auxiliary heat was applied to the hands at -20^{o} F., pegboard performance on periods two through four correlated significantly only with hand skin temperature at the little and middle fingers.

CONCLUSIONS/RECOMMENDATIONS:

(1) For the present experiment, local cooling of the hand and forearm is the determining factor for manual dexterity in the cold.

(2) Auxiliary heat applied to the hands under cold conditions results in no impairment of manual performance in temperatures as low as 0^{o} F. At -20^{o} F. performance impairment can be attenuated through the use of auxiliary heat.

(3) Although attempts to correlate performance and digital temperature during cold exposure have been unsuccessful in previous studies, there was some evidence in the present experiment for patterns of relationships between performance and HST at different recording sites.

ENVIRONMENT: COLD

AUTHORS: Payne, R. B.

TITLE: Tracking proficiency as a function of thermal balance.

CITATION: Journal of Applied Physiology, 1959, 14, 387-389.

PURPOSE: The purpose of this study was to determine (a) whether or not performance decrement in monitoring and controlling a complex visual display is related to body heat loss and (b) whether or not such an impairment can be forestalled by glycine administration.

METHODOLOGY:

SUBJECTS: The subjects were 72 volunteer airmen.

EQUIPMENT: The experimental task was provided by the USAF SAM Multidimensional Pursuit Test (CM 813 E).

PROCEDURE: The task required the subject to monitor the movements of four eccentrically driven instrument pointers and to keep them within prescribed scale areas by coordinated adjustments of several simulated aircraft controls. A score was recorded only when all pointers were kept within the prescribed areas concurrently. On each of 36 experimental days two subjects received 50 one minute training trials with a 15 second intertrial interval. These trials were conducted in a thermostatically controlled chamber at 70°F. After resting for 30 minutes at room temperature, the subjects were reassigned to one of nine combinations of three ambient temperatures (70°, 55°, or 40°F) and three glycine treatments (2 grams saccharin, 20 grams glycine, or 40 grams glycine). Glycine was administered after 20 minutes of room temperature rest. Ten minutes later they began the experimental session of 160 one minute trials with the same intertrial interval.

SIGNIFICANT RESULTS: Task proficiency as a function of temperature declined equally in all conditions up to 50 minutes of work at which point the subjects in the 40°F condition began a more rapid decline. This effect was significant at $p < .05$. Maximum proficiency occurred at 50°F. Task proficiency decrement as a function of glycine treatment was equal for all conditions. There was no interaction between the glycine and temperature conditions.

CONCLUSIONS/RECOMMENDATIONS: Glycine effects, whatever merit they may have in terms of thermoregulatory response, were not evident in the performance data presented above. Concerning temperature, investigators typically report 70-75°F as the optimum temperature for peak performance of perceptual-motor skills. However, the present data show 50°F to be the optimum temperature. Such discrepancies may be due to different clo values of subjects. Also, it is possible that certain tasks profit from more intense and varied cutaneous and proprioceptive inputs arising from a cooler environment.

ENVIRONMENT: COLD

AUTHORS: Provins, K. A. and Clarke, R. S. J.

TITLE: The effect of cold on manual performance.

CITATION: Journal of Occupational Medicine, 1960, 2, 169-176.

PURPOSE: The purpose of this article was to review and integrate the literature on manual performance in the cold.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Reaction Time--Results of reaction time studies indicate that at low ambient temperatures there may be some impairment of performance, particularly if there is local cooling of the hand and the response requires more than a light operating pressure. More evidence is needed in this area.

(2) Tracking Proficiency--Results of nearly every investigation involving tracking performance have indicated appreciable impairment at low ambient temperatures. Tracking tasks may be expected to suffer some performance decrement at temperatures below about 10° C (50° F).

(3) General Dexterity--Results suggest that local cooling of the hand or arm usually produces a significant impairment of manual dexterity irrespective of the general body temperature (within limits). Reduction of general body temperature may not be accompanied by a reduction in manual dexterity as long as the hands and arms are kept warm.

ENVIRONMENT: COLD

AUTHOR: Teichner, W. H.

TITLE: Manual dexterity in the cold.

CITATION: Journal of Applied Physiology, 1957, 11, 333-338.

TEICHNER, WARREN H. *Manual dexterity in the cold.* J. Appl. Physiol. 11(3): 333-338. 1957.—The effects of the cold on manual dexterity were studied by relating performance time on the Minnesota Rate of Manipulation Test to air temperature and velocity, windchill, mean surface skin temperature, digital temperature of the working hand and rate of digital cooling using data from 530 subjects sorted into 14 different combinations of air temperature and wind for an exposure period of approximately 60 minutes. Air temperature and windchill were found to increase performance time significantly; wind velocity did not have a significant effect by itself; mean surface skin temperature was slightly, but significantly, inversely correlated with performance time only for nude men; digital cooling rate and digital temperature were not demonstrated to be related to performance time.

ENVIRONMENT: COLD

AUTHOR: Teichner, W. H.

TITLE: Reaction time in the cold.

CITATION: Journal of Applied Psychology, 1958, 42, 54-59.

Visual reaction times were elicited from 620 soldiers sorted into 14 different groups representing a variety of ambient temperatures, windspeeds and windchills. Included were two groups at 60°F., five mph, one of which was nude and the other lightly clothed. Reaction time was measured after 45 minutes of exposure and again following a short, mild exercise, after 65 minutes of exposure. In addition, mean area-weighted skin temperatures were obtained. The following colclusions drawn from the results apply to the effects of the cold on "non-acclimatized" and/or "non-habituated" men, not in physiological distress:

1. At low windspeed, at least up to five mph, low ambient temperature has no effect on reaction time, at least down to -35°F. and probably down to -50°F.

2. At windspeeds of 10 mph and greater, low ambient temperature produces a significant decrease in reaction time.

3. Windspeed produces a significant decrease in reaction time.

4. Mild exercise produces a small recovery in reaction time.

5. If men of low "physiological cold tolerance" are removed from the more severe environmental conditions and if subjects wear protective clothing, reaction time is essentially a linear decreasing function of windchill.

6. It was hypothesized that the reaction time function obtained is psychological in nature; a specific hypothesis of "psychological cold tolerance" was proposed.

ENVIRONMENT: COLD

AUTHORS: Teichner, W. H. and Kobrick, J. L.

TITLE: Effects of prolonged exposure to low temperature on visual-motor performance.

CITATION: Journal of Experimental Psychology, 1955, 49, 122-126.

Five *Ss* lived in a constant temperature chamber for 41 days. For the first 16 days the temperature was held at 75°, for the next 12 at 55°, and for the remaining 13 days at 75° F. The *Ss* were given 15 trials daily on the pursuit rotor. The data obtained appear to allow the following conclusions regarding the effects of prolonged exposure to low ambient temperature:

1. Visual-motor performance is markedly and immediately impaired in the cold and recovers gradually, but to a lower limit than it attains under optimal temperature conditions.
2. The impairment of visual-motor performance in low temperature is the result of a lowering of the final limit of performance rather than a reduction of the rate or limit of learning.
3. Under conditions of massed practice temporary work decrement is not influenced by practice and affected slightly or not at all by lowered ambient temperature.

ENVIRONMENT: COLD

AUTHORS: Teichner, W. H. and Wehrkamp, R. F.

TITLE: Visual-motor performance as a function of short duration ambient temperature.

CITATION: Journal of Experimental Psychology, 1954, 47, 447-450.

Time-on-target measures on the pursuit rotor were obtained from four subject groups which practiced for short periods on five successive days under ambient temperatures of 55°, 70°, 85°, and 100° F., respectively. Performance was found to be poorer at temperatures above and below 70° F. This result confirms and extends previous studies of the effects of ambient temperature. In addition, the data suggest the possibility that the temperature function falls off more rapidly with temperatures lower than the maximum than it does for those that are higher.

THE VIBRATION ENVIRONMENT

PSYCHOMOTOR PERFORMANCE REVIEW

AND ANNOTATED BIBLIOGRAPHY

INTRODUCTION

Vibration is the periodic displacement or oscillation of a mass over time. Man is subjected to vibration in many of the systems in which he is an integral part (e.g. aircraft, ships, etc.); thus it is important that engineers, designers, and psychologists, as well as the many others involved in the design of man-machine systems, be familiar with vibration effects upon psychomotor performance. The following paper attempts to review and integrate the effects of vibratory environment upon man's psychomotor performance.

Reaction Time and Cognitive Tasks

Tasks composed of factors indicative of primarily central rather than peripheral neural processes, such as reaction time, pattern recognition, monitoring, and vigilance, typically are unaffected by a vibrating environment (Grether, 1971). Several investigators have studied the effect of vibration on simple, choice, and complex reaction time and found no effect regardless of frequency, axis, duration, or periodicity of vibration (Coermann, 1938; Schmitz 1959; Hornick, 1962; Dudek and Clemens, 1965; Hornick and Lefritz, 1966; Shoenberger, 1970). Cognitive type tasks composed of factors such as pattern recognition, display monitoring, and vigilance also appear unaffected by vibration (Schohan, Rawson, and Soliday, 1965; Weisz, Goddard, and Allen, 1965; Shoenberger, 1967).

Manual Dexterity

Tasks requiring manual dexterity, foot movement responses, and fine control sensitivity/maintenance have also been studied

in a vibrating environment. In general, manual dexterity is unaffected by vibration (Loeb, 1955; Simons, and Schmitz, 1971). However, tasks involving fine control sensitivity and/or maintenance are degraded due to vibration, the decrement being greater at increased frequencies with a constant g level, or simply increased amplitude (Guignard and Irving,1960; Hornick, 1962; Chaney and Parks, 1964). This is to be expected since the vibration levels used in research are not of sufficient amplitude to affect the grosser movements involved in manual dexterity, but are large enough to interfere with more finely controlled muscular movements.

Tracking

Much research has been done on the effects of vibration on two dimensional compensatory tracking which appears to be composed of three factors: fine control sensitivity, response orientation, and movement analysis. It has been found that tracking performance is degraded by vibration (Parks, 1961; Catterson, Hoover, and Ashe, 1962; Hornick, 1962; Buckhout, 1964; Chaney and Parks, 1964; Harris, Chiles, and Touchstone, 1964; Weisz, Goddard, and Allen, 1965; Holland, 1967; Lovesey, 1968; Shoenberger, 1970). Furthermore, three relationships exist between tracking decrement and vibration. Firstly, greatest tracking error occurs in the same axis as the corresponding vibrational axis (Parks, 1961; Buckhout, 1964; Shoenberger, 1970). This is to be expected since sinusoidal vibration in the same direction as an intended muscular movement

would have a tendency to cause lead or lag errors. Fine control sensitivity, previously shown to be affected by vibration, would be even more affected with greatest sensitivity required in one direction. Secondly, decrement appears to be related to the amplitude rather than the frequency of vibration (Catterson, Hoover, and Ashe, 1962; Hornick, 1962; Buckhout, 1964; Harris, Chiles, and Touchstone, 1964; Weisz, Goddard, and Allen, 1965; Harris and Shoenberger, 1966; Holland, 1967; Lovesey, 1968). Furthermore, it appears that at a relatively low frequency level (approximately 5 cps) little or no performance deterioration will be observed at amplitudes at or below 0.16 inches displacement (Harris, Chiles, and Touchstone, 1964; Holland, 1967). This finding is consistent with previous results indicating that fine control sensitivity is reduced with increasing amplitude levels of vibration. And finally, with g force held constant, tracking decrement is greatest at the lower freuqencies, since with a constant g level, amplitude relatively increases as frequency is reduced.

The two other factors involved in two dimensional compensatory tracking, response orientation and movement analysis, are of a more cognitive nature in that no muscular movements are involved. Therefore, one can conclude that vibration would not affect these factors since it was shown previously that cognitive type tasks such as pattern recognition, monitoring, and vigilance are unaffected by a vibrating environment.

Conclusions

To summarize, it appears that of the factors studied under vibration conditions, those factors indicative of central rather than peripheral neural processes such as reaction time, pattern recognition, monitoring, vigilance, response orientation, and movement analysis, are unaffected by vibration. The only factor which consistently shows a decrement under the vibration levels typically used is that of fine control sensitivity. However, even fine control sensitivity appears unaffected at frequencies of 5 cps or lower when amplitude levels are at or below 0.16 inches displacement.

Table 8

Summary of Surveyed Articles

References	Environment	Factors Measured
Buckhout, R. (1964)	Vibration	Manual Dexterity, Fine Control Sensitivity, Movement Analysis
Bush, R. L., Davis, A. S., Jamar, L. G., and Mushtaq, M. (1965-66)	Vibration	Manual Dexterity, Finger Dexterity
Catterson, A. D., Hoover, G. N., and Ashe, W. F. (1962)	Vibration	Fine Control Sensitivity, Response Orientation, Movement Analysis
Chaney, R. E., and Parks, D. L. (1964)	Vibration	Manual Dexterity, Fine Control Sensitivity, Response Orientation, Time Sharing
Chaney, R. E., and Parks, D. L. (1964)	Vibration	Manual Dexterity, Multi-Limb Coordination, Fine Control Sensitivity, Movement Analysis
Clemens, D. E. (1964)	Vibration	Reaction Time, Response Orientation, Speed of Arm Movement, Perceptual Speed
Coermann, R. R. (1938)	Vibration	Reaction Time
Coermann, R. R., Magid, E. B., and Lange, K. O. (1962)	Vibration	Motor Kinesthesis
Dean R. D., Farrell, R. J. and Hitt, J. D. (1969)	Vibration	Reaction Time, Manual Dexterity, Finger Dexterity, Fine Control Sensitivity
Dennis, J. P. (1965)	Vibration	Undetermined

Table 8 (continued)

References	Environment	Factors Measured
Dudek, R. A., and Clemens, D. E. (1965)	Vibration	Reaction Time, Response Orientation, Speed of Arm Movement, Perceptual Speed
Fraser, T. M., Hoover, G. N., and Ashe, W. F., (1961)	Biration	Manual Dexterity, Fine Control Sensitivity, Movement Analysis
Guignard, J. C., and Irving, A. (1960)	Vibration	Reaction Time, Manual Dexterity, Fine Control Sensitivity, Speed of Arm Movement, Perceptual Speed, Aiming
Harris, C. S., and Shoenberger, R. W. (1966)	Vibration	Manual Dexterity, Fine Control Sensitivity, Movement Analysis
Harris, C. S., and Sommer, H. C. (1973)	Vibration	Manual Dexterity, Fine Control Sensitivity, Movement Analysis
Hornick, R. J. (1962)	Vibration	Reaction Time, Manual Dexterity, Multi-Limb Coordination, Response Integration, Spatial Relations, Movement Analysis, Perceptual Speed, Time Sharing
Hornick, R. J. and Lefritz, N. M. (1966)	Vibration	Reaction Time, Vigilance
LaRue, M. A. Jr., (1965)	Vibration	Fine Control Sensitivity, Response Orientation
Loeb, M. (1955)	Vibration	Arm-Hand Steadiness, Fine Control Sensitivity, Wrist-Finger Speed, Mirror Tracing
Parks, D. L. (1961)	Vibration	Manual Dexterity, Fine Control Sensitivity, Movement Analysis

Table 8 (continued)

References	*Environment*	Factors Measured
Schmitz, M. A. (1959)	Vibration	Reaction Time
Schohan, B., Rawson, H. E., and Soliday, S. M. (1965)	Vibration	Vigilance
Shoenberger, R. W. (1970)	Vibration	Reaction Time, Fine Control Sensitivity, Response Orientation, Movement Analysis, Perceptual Speed, Time Sharing
Shoenberger, R. W. (1967)	Vibration	Undetermined
Simmons, A. K. and Schmitz, M. A. (1959)	Vibration	Fine Control Sensitivity, Wrist-Finger Speed
Weisz, A. A., Goddard, C., and Allen, R.W. (1965)	Vibration	Vigilance

Table 9

Summary of Articles by Factor Measured

Factor Measured	
1. Reaction Time	Clemens (1964) Coermann (1938) Dean, Farrell, and Hitt (1969) Dudek and Clemens (1965) Guignard and Irving (1960) Hornick (1962) Hornick and Lefritz (1966) Schmitz (1959) Shoenberger (1970)
2. Manual Dexterity	Buckhout (1964) Bush, Davis, Jamar, and Mushtaq (1965-66) Chaney and Parks (1964) Chaney and Parks (1964) Dean, Farrell, and Hitt (1969) Fraser, Hoover, and Ashe (1961) Guignard and Irving (1960) Harris and Shoenberger (1966) Harris and Sommer (1973) Hornick (1962) Parks (1961)
3. Finger Dexterity	Bush, Davis, Jamar, and Mushtaq (1965-66) Dean, Farrell, and Hitt (1969)
4. Multi-Limb Coordination	Chaney and Parks (1964) Hornick (1962)
5. Arm-Hand Steadiness	Loeb (1950)
6. Fine Control Sensitivity	Buckhout (1964) Catterson, Hoover, and Ashe (1964) Chaney and Parks (1964) Chaney and Parks (1964) Dean, Farrell, and Hitt (1969)

Table 9 (continued)

Factor Measured	References
	Fraser, Hoover, and Ashe (1961) Guignard and Irving (1960) Harris and Shoenberger (1966) Harris and Sommer (1973) LaRue (1965) Loeb (1955) Shoenberger (1970) Simmons and Schmitz (1959)
7. Response Orientation	Catterson, Hoover, and Ashe (1962) Chaney and Parks (1964) Clemens (1964) Dudek and Clemens (1965) LaRue (1965) Shoenberger (1970)
8. Speed of Arm Movement	Clemens (1964) Dudek and Clemens (1965) Guignard and Irving (1960)
9. Motor Kinesthesis	Coermann, Magid, and Lange (1962)
10. Response Integration	Hornick (1962)
11. Spatial Relations	Hornick (1962)
12. Wrist-Finger Speed	Loeb (1955) Simmons and Schmitz (1959)
13. Position Estimation	None Found
14. Position Reproduction	None Found
15. Movement Analysis	Buckhout (1964) Catterson, Hoover, and Ashe (1962)

Table 9 (continued)

Factor Measured	References
	Chaney and Parks (1964) Fraser, Hoover, and Ashe (1961) Harris and Shoenberger (1966) Harris and Sommer (1973) Hornick (1962) Parks (1961) Shoenberger (1970)
16. Perceptual Speed	Clemens (1964) Dudek and Clemens (1965) Guignard and Irving (1960) Hornick (1962) Shoenberger (1970)
17. Time Sharing	Chaney and Parks (1964) Shoenberger (1970)
18. Mirror Tracing	Loeb (1955)
19. Aiming	Guignard and Irving (1960)
20. Vigilance	

ENVIRONMENT: VIBRATION +1 Hz

AUTHOR: Buckhout, R.

TITLE: Effect of whole body vibration on human performance.

CITATION: Human Factors, 1964, 6, 157-163.

The effects of whole-body vibration at frequencies of 5, 7, and 11 c's from 25–35 per cent of the human tolerance levels defined by amplitude levels within each frequency) are to seriously reduce operator efficiency in performing tasks representative of those encountered in aerospace flight. Within the limits of the vibration conditions studied, the following conclusions were drawn from the research: (1) Decrements in vertical tracking performance ranged from 34 to 74 per cent. (2) Decrements in horizontal tracking performance ranged from 10 to 48 per cent. (3) The magnitude of the tracking performance decrements was related to the magnitude of integrated absolute G_z (output) measured at the sternum. (4) More procedural errors were committed under vibration than under static conditions.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Bush, R. L., Davis, A. S., Jamar, L. G., and Mushtaq, M.

TITLE: The effect of vibration on fine hand motions.

CITATION: Unpublished manuscript, Texas Tech University, 1965-1966.

PURPOSE: The purpose of this investigation was to explore the effects of vertical vibration within the limits encountered in industry and the transportation medium upon the ability to perform certain types of fine hand motions--typing in this case.

METHODOLOGY:

SUBJECTS: The subjects were four right-handed females of equivalent typing ability, age, height, and weight.

EQUIPMENT: A mechanical shake table with an unpadded laboratory stool and backrest was used to impart vibration to the subject. The stool was adjustable in height with respect to the work station on which an IBM Selectric typewriter was mounted.

PROCEDURE: The vibration levels were composed of all combinations of three frequency levels--3, 6, and 9 cps and three amplitudes--0.05, 0.10, and 0.15 inches. In addition, there were three varying test durations--2, 4, and 8 minutes. A replication condition was achieved by repetition of each of the 27 combinations of the above three variables with each of the four subjects. Each subject received five minutes of warm-up typing under no vibration and five minutes rest between each vibration level. The dependent variables were performance rate per minute and errors per 100 words.

SIGNIFICANT REUSLTS: Regarding performance rate neither frequency, amplitude, test duration, nor any of the interactions were significant at the $p < .05$ level. Regarding error rate errors increased with each increase in amplitude level. The error rate at 6 cps was nearly double that at 3 and 9 cps. Interaction effects between frequency and amplitude were as follows:

(1) At 3 cps error rate decreased as amplitude increased.
(2) Error rate was highest at 6 cps for each amplitude level, the maximum combination being 6 cps, 0.15 inch.
(3) At 9 cps error rate increase was negligible.

Test duration had no effect on any of the dependent variables.

CONCLUSIONS/RECOMMENDATIONS: Within the scope of this experiment performance rate was not affected by vibration. Since this task was selected to simulate the fine hand motions involved in assembly work this lack of effect was unexpected. Error rate under vibration increased over 300% as compared to the no vibration condition. The significant increase in error rate at 6 cps was believed due to the existence of the resonant frequency of the sitting body at this level; a finding of previous experimenters which this result appears to confirm. Furthermore, the lack of an effect at 3 cps, the natural frequency of the shoulder-arm complex, is believed due to the standard task selected. In conclusion, it appears that the effect on the basic body posture involved in the task is a more important determinant of performance than the effect on the particular body limb involved. To test this possibility future studies with subjects in a standing position at frequencies of 5 and 11 cps, the natural frequencies of the standing body, should be conducted with foot and lever actuations.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Catterson, A. D., Hoover, G. N., and Ashe, W. F.

TITLE: Human psychomotor performance during prolonged vertical vibration.

CITATION: Aerospace Medicine, 1962, 33, 598-602.

PURPOSE: The purpose of this study was to explore changes in amplitude and frequency on the ability of unrestrained human subjects to perform a tracking task under vertical vibration.

METHODOLOGY:

SUBJECTS: The subjects were five volunteer graduate students from the Department of Physical Education at Ohio State University.

EQUIPMENT: The vibration source was a mechanical shake table with a non-dampening wood and steel chair with backrest. A problem display panel was mounted on the shake table with a control stick between the subjects' knees.

PROCEDURE: Each subject performed a tracking task under all combinations of six discrete frequencies and two amplitudes: 2, 4, 6, 8, 11, and 15 cps and 0.065 and 0.013 inches displacement. The tracking task consisted of a light moving continuously over the entire face of the display panel in a constantly changing cyclic pattern. A central white light represented the point where the resultant electrical signal was equal to zero in both the lateral and the to and fro axis of the board. The subject's task was to maneuver the control stick in such a way as to keep the central white light on at all times. An error score was obtained by measuring the integral of the distance the light was away from the neutral central position with respect to time. Each error score was the sum of the above for a 58.5 second time period. Each subject performed the task for two five minute periods during both 12 20 minute control sessions (no vibration) and 12 20 minute vibration sessions (one session for each levvel of frequency x amplitude). A five minute rest period was instituted between each control and experimental session. During each five minute tracking session errors were sampled twice.

SIGNIFICANT RESULTS: The average change in error between the control period and the vibration period was calculated for each separate condition of vibration as was the error score during the early and late part of vibration. These results were subjected to an analysis of variance to test for differences between frequencies alone, between frequencies alone, between amplitudes alone, between the interaction of amplitude and frequency at each level of vibration, and between the early and late tracking periods during vibration. It was found that:

(1) Error decreased at all frequencies of 0.06 inch amplitude.
(2) Error increased at all frequenices of 0.13 inch amplitude.
(3) There was no significant error differences between early and late tracking periods.
(4) Changes in frequency were associated with error changes at the $p < .01$ level.
(5) The interaction of frequency x amplitude was significant at the $p < .01$ level.
(6) Amplitude changes were associated with error changes at the $p < .0001$ level.

CONCLUSIONS/RECOMMENDATIONS: While task performance did decrease as a function of vibration severity, this deterioration was largely due to the amplitude changes regardless of differences in frequency. Therefore, equations relating the severity of vibration to levels of acceleration (G's) are not valid since acceleration is proportional to amplitude times frequency squared. The above data indicate that any mathematical expression of vibration severity should recognize amplitude as the dominant contributing factor.

ENVIRONMENT: VIBRATION +1 Hz

AUTHOR: Chaney, R. E. and D. L. Parks

TITLE: Visual-motor performance during whole-body vibration.

CITATION: Technical Report No. D3-3512-5, Human Factors Staff, The Boeing Co., Wichita, Kansas, November 1964. (NTIS No. AD-456-271)

Seven male employees of the Boeing Company were tested in the company's human vibration facility to determine the effect of whole body vibration on visual-motor performance. Six controls; a large and a small knob; a horizontal and a vertical lever; and a horizontal and a vertical thumbwheel were used to adjust a standard 3-inch dial indicator to a prescribed setting. Independent variables included variations in vibration frequency and severity, control force requirements, and task complexity. Speed and accuracy of task accomplishment were recorded for each condition.

A high work load condition, vibration independent of frequency and level, and control force requirements, individually affected the speed and accuracy of operator adjustment. The type of control used did not influence accuracy, and had only minor influence on adjustment time with mounting position apparently producing the noted differences.

ENVIRONMENT: VIBRATION +1 Hz

AUTHOR: Chaney, R. E., & Parks, D. L.

TITLE: Tracking performance during whole body vibration.

CITATION: Document No. D3-3512-6, The Boeing Co., Wichita, Kansas, November 1964. (NTIS No. AD-456-277)

ABSTRACT

Seven male volunteers were tested in the Boeing vibration facility to determine the effect of whole body vertical vibration on tracking performance. Compensatory wheel, column and foot tracking data were obtained at each of four subjective reaction levels at frequencies ranging from 1 through 27 cycles/second.

A perfect correlation between subjective vibration experience and tracking performance degradation was noted. The largest degree of error was produced in the 10 through 20 cps range with vibration severity (reaction level) differentially affecting the critical frequencies. Foot tracking performance improved as control forces were increased with less improvement shown under vibration than the non-vibrating control condition.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Clemens, D. E.

TITLE: The effect of vibraiton on certain psychomotor responses.

CITATION: Unpublished master's thesis, Texas Tech University, 1964.

PURPOSE: This thesis investigated the effect of vertical, whole-body vibration at all combinations of the frequencies 4, 8, and 12 cps and amplitudes of 0.15, 0.20, and 0.25 inches on reaction and performance times in the execution of the simple hand movements of extension, flexion, and supination.

METHODOLOGY:

SUBJECTS: The subjects were 27 males between 18 and 32.

EQUIPMENT: The device used to impart vibration was a mechanical shake table on which was mounted a work station and a laboratory stool with a backrest. Subjects were restrained by a lap belt. Three switches were mounted on the work station--a pushbutton type switch, a toggle switch, and a rotary selector type switch. A red light was located above each.

PROCEDURE: Subjects were instructed to observe all the switches simultaneously and to activate the switch under which the red light flashed. Each switch was operated five times during each of three test periods. Data was recorded on both of the main effects of reaction and performance time, performance time being measured by a telegraph key which the subject depressed continuously while waiting for a red light to flash.

SIGNIFICANT RESULTS: Considering reaction time only, two trends appeared:

(1) At 4 cps increments in amplitude produced decrements in reaction time.
(2) At 0.20 and 0.25 inch amplitude increments in frequency produced decrements in reaction time.

Considering performance time only, two trends appeared:

(1) At 4 cps increments in amplitude produced decrements in performance time.
(2) At 12 cps increments in amplitude produced increments in performance time.

Apart from the above trends, neither frequency nor amplitude was significant factor affecting reaciton or performance time.

CONCLUSIONS/RECOMMENDATIONS: Vibration had no effect on reaction time other than a possible influence on the first post-vibration trial. It was concluded that the relationships between flexion and extension movements for static conditions also holds for conditions of vibration. It was emphasized that the results not be thought contradictory to those of tracking tasks which typically show a performance decrement under vibration, rather, the author contended that the effect of vibration on performance is a function of the task or elemental motion.

ENVIRONMENT: VIBRATION +1 Hz

AUTHOR: Coermann, R. R., Magid, E. B., & Lange, K. O.

TITLE: Human performance under vibration stress.

CITATION: Human Factors, 1962, 4, 315-324.

Blindfolded subjects, restrained by standard harness, sat on a modified Air Force chair, which was programmed to move in random patterns in pitch and roll, the subjects counteracting these motions by using a control stick. The whole device was itself mounted on a mechanical shake table producing vertical sinusoidal motion at frequencies ranging from 2 c/s to 20 c/s and at amplitudes corresponding to about one-third of the subjective tolerance limits. The angular deviations from the upright position were evaluated relative to the disturbing input for both pitch and roll, one minute during the vibration experience and one minute after cessation of the vibration. Some individual subjects were not influenced by the vibration; others showed performance decrements. In the mean, these measures of human performance reflect all mechanical resonances within the body, previously established by other methods. The frequencies most affecting performance were found to be between 3 and 12 c/s. Residual effects were detected by the measurements after vibration.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Dean, R. D., Farrell, R. J., and Hitt, J. D.

TITLE: Effect of vibration on the operation of decimal input devices.

CITATION: Human Factors, 1969, 11, 257-272.

PURPOSE: The purpose of this study was to explore the effects of five levels of random vertical vibration on the speed and accuracy of decimal input device operation.

METHODOLOGY:

SUBJECTS: The subjects were 10 volunteer qualified pilots.

EQUIPMENT: A shake table was used to provide random vertical vibration with a rigid seat (0.5 inches of felt to provide padding). Subjects were restrained by a lap belt and shoulder straps. Three types of decimal input devices were used: push button matrix, rotary switch-array, and thumbwheel-array.

PROCEDURE: A single test session consisted of operating one decimal device for 25 minutes under all five levels of random vertical vibration--2-30 Hz, 0.0, 0.2, 0.4, 0.6, and 0.8 RMSg. Five minutes were spent on each device. Prior to a test session each subject received five minutes of training on the particular device for that day under no vibration followed by 15 seconds of exposure time to each vibration level. The task consisted of entering an eight digit number identical to the one displayed before him. The subject then checked the number for errors and either corrected it (if the device allowed for error correction) or pressed an "error" button. If no errors were found the subject entered "no errors". Variables measured were insertion time and error probability.

SIGNIFICANT RESULTS: The analysis of variance of insertion time revealed that both the vibration level and the type of device significantly affected input time ($p < .01$). Duncan's Multiple Range Test indicated that input times for the two highest vibration levels, 0.6 and 0.8 RMSg, were equivalent and were significantly greater than for the other three levels which were equivalent to each other ($p < .01$). The interaction between devices and vibration was statistically significant, the change in input time under vibration being greatest for the thumbwheel array and least for the rotary array.

The effect of vibration was not statistically significant for any of the indexes of accuracy. The interaction between vibration level and devices was statistically significant for both total and unrecognized digit errors ($p < .01$). With the push button matrix the highest vibration level yielded the most errors, with the thumbwheel array it yielded the fewest.

CONCLUSIONS/RECOMMENDATIONS: The outstanding feature of this data is that all subjects continued to perform in an integrated manner at all levels of vibration. It appears that after practicing on a particular decimal input device subjects were able to maintain accuracy under high levels of vibration by taking more time to insert the number. However, average insertion time never exceeded two seconds more than that required under the no vibration condition. Furthermore, vibration levels of 0.4 RMSg or less had no effect on speed with the rank-order of devices by speed remaining constant regardless of the vibration level.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Dennis, J. P.

TITLE: The effect of whole-body vibration on a visual performance task.

CITATION: Ergonomics, 1965, 8, 193-205.

PURPOSE: This study investigated the relationship between visual performance and the frequency and amplitude of head movement.

METHODOLOGY:

SUBJECTS: Twelve subjects, all with adequate vision to perform the task, were used.

EQUIPMENT: A tank driver's seat mounted on a vibration table was used to vibrate each subject with an accelerometer of a crystal type used to measure vertical head movement. The accelerometer was attached to a metal plate on top of a leather helmet worn by each subject. The amplitude of the acceleration trace was read from an oscilloscope.

PROCEDURE: The subject's task was to read aloud 10 groups of 40 numbers each. An error was recorded if any digit was read aloud incorrectly. The time taken to read the numbers was recorded by a stopwatch. Two acceleration levels of table vibration were selected--½g and 1g hereafter referred to as Light and Heavy. A range of frequencies (5-37 cps) and amplitudes (0.15-5.1) was calculated which would give these conditions. Each subject attended six separate sessions, experiencing one of the amplitude conditions at two levels of frequency at each session with the order of Light and Heavy randomized. Each session consisted of: No Vibration; Vibration (Light or Heavy); No Vibration; Vibration (Heavy or Light); No vibration. Head movement was measured on each subject three times during each vibration condition: immediately before, during, and immediately after the visual performance task. The error data were analyzed in three ways: (a) analysis of Light and Heavy results separately, (b) comparison of Light and Heavy results, (c) determination of significance between treatment and corresponding non-vibration means.

SIGNIFICANT RESULTS: The general trend of results of the analysis of head movement showed a marked reduction in movement transmitted to the head as frequency increased. Concerning the error analysis averaged over all subjects,

errors significantly increased by about 21% under Light vibration and by 54% under Heavy vibration. Response times were approximately 3% longer under Light vibration and 10% longer under Heavy vibration. However, these increases in response times were not statistically significant. Three additional results were as follows:

(1) At each of the six amplitudes of table movement the increase in frequency from Light to Heavy produced one or both of two results:
  (a) a significant decrease in amplitude of head movement
  (b) a significant increase in error
(2) Very small amplitudes of head movement produced significant decrements at higher frequencies.
(3) All Heavy vibration conditions reuslted in a statistically high significant increase in errors.

CONCLUSIONS/RECOMMENDATIONS: The above findings support previous research which suggests that vibration of the body has different effects from vibration of the visual field and that this difference is due to the resonance characteristics of the eye.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Dudek, R. A., and Clemens, D. E.

TITLE: Effect of vibration on certain psychomotor responses.

CITATION: Journal of Engineering Psychology, 1965, 4, 127-143.

PURPOSE: The purpose of this study was to investigate the effect of vertical vibration typically enocuntered in industrial settings on the reaction and performance times of certain hand movements.

METHODOLOGY:

SUBJECTS: The subjects were 27 right-handed males between 18 and 32.

EQUIPMENT: Equipment used were a mechanical shake table with work station and seat, a push-button-type switch, a standard commercial toggle switch, a rotory selector-type switch, and a telegraph key.

PROCEDURE: Before each test, the shake table was set for one of three possible amplitudes and one of three possible frequencies. They were, respectively, 0.15, 0.20, or 0.25 inches and 4, 8, or 12 cps. Each trial began with the subject depressing the telegraph key with his right hand. When a red light on the console came on the subject immediately activated the switch directly beneath it. The subject again pressed the telegraph key when the light went off thus beginning another trial. Three test periods were conducted with each switch type operated five times per period. Reaction time was measured from the onset of the light to the release of the telegraph key. Performance time was measured from the release of the telegraph key to the completion of the switch operation.

SIGNIFICANT RESULTS: Two separate analyses of variance were conducted on the dependent variables of reaction and performance time. A multivariate analysis was conducted on all factors in which the dependent variable was called "score" and included both reaction and performance time. Cycle time was defined as being the sum of the mean reaction and mean performance time. Reaction time was found to be relatively constant as compared to the control period. The interactions of frequency x score and amplitude x score indicated that increased frequency produced a divergence between reaction and performance time with the converse being true for increased amplitude. Neither frequency nor amplitude main effects significantly

affected reaction or performance times. In agreement with previous literature mean performance time for the extension movement was 8% faster than for the flexion movement. However, the relationship between the supine movement and vibration levels appeared much more complex with frequency being the confusing factor.

CONCLUSIONS/RECOMMENDATIONS: This research did not support previous findings concerning vibration and motor responses. However, the vibrations used above were lower than in most other studies. The authors concluded that "the effect of vibration on performance is a function of the task or elemental motion". Concerning the interactions of frequency x score and amplitude x score it was suggested that subjects compensate for a longer reaction time with a shorter performance time and vice versa. However, this merely describes the effect, it does not explain it. Perhaps if the experiment were repeated with vibration levels in accordance with previous research concurring results might be obtained. At any rate the relationship between frequency of vibration and the supine movement needs to be explicated.

ENVIRONMENT: VIBRATION +1 Hz

AUTHOR: Fraser, T. M., Hoover, G. N., & Ashe, W. F.

TITLE: Tracking performance during low frequency vibration.

CITATION: Aerospace Medicine, 1961, 32, 829-835.

Conclusions

The conclusions from this study are that within the range of amplitudes, frequencies, and planes examined, in unrestrained subjects without artificial damping, exposure to harmonic sinusoidal vibration produces a decrement in tracking performance related primarily to the amplitude of vibration, although the function involved is probably modified by a dynamically varying function or functions of frequency. Performance is also observed to vary with the plane of vibration, the greatest decrement occurring in the vertical and transverse planes. Vertical and horizontal control of a display is also found to vary with the plane of vibration. A significant but inconsistent decrement is observed under most circumstances when the display does not vibrate in conjunction with the subject.

Summary

Healthy subjects were exposed to harmonic sinusoidal vibration in forty-eight randomly selected combinations of three planes, four frequencies, and four amplitudes, namely 2,4,7, and 12 cps, and ± 1/16, 1/8 3/16, and 1/4 inch. After training to proficiency in the nil vibration state, the subjects' performance of a similarly vibrating tracking task was measured. Measurements were also made of the ability of vibrating subjects to track a non-vibrating task.

Decrement in performance was observed related to plane, and to function of amplitude modified by a fractional exponent of frequency. The significance of this is discussed.

A significant difference was observed between the performance of a vibrating task and a non-vibrating task.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Grether, W. F.

TITLE: Vibration and human performance.

CITATION: Human Factors, 1971, 13, 203-216.

PURPOSE: This article reviewed the effects of vibration ranging from 1 to 30 Hz on human performance. Only those studies dealing with psychomotor performance not summarized elsewhere will be reviewed here.

METHODOLOGY: NA

SIGNIFICANT RESULTS:

Reaction Time and Perceptual Judgements

Coermann (1938) studied a four choice reaction time test at 30-1000 Hz and found no consistent effects.
Schmitz (1959) measured simple foot reaction time at low frequency levels and found no effect.
Weisz, Goddard, and Allen (1965) studied auditory vigilance and visual display monitoring under sinusoidal and random vibration, with neither task yielding a decrement.

Tracking

Parks (1961) found greatest tracking error in the same axis as the corresponding vibration under Z axis sinusoidal and sinusoidal vibration.
Harris and Shoenberger (1966) found that at a constant g level, tracking decrement is greatest at the lower frequencies.

Other

Loeb (1955) studied mirror tracing, tapping speed, manual steadiness, and hand grip. Only manual steadiness was affected.
Schmitz (1959) studied hand tremor, body sway, and foot pressure with the latter task showing the only decrement.
Simons and Schmitz (1958) found significant effects for body sway and foot pressure, but not tapping rate.

CONCLUSIONS/RECOMMENDATIONS: Three salient generalizations can be made regarding vibration effects and psychomotor performance:

1. Vibration degrades tracking performance in proportion to vibrational amplitude and is greatest at or below 5 Hz.

2. Vibration degrades performance on tasks requiring steadiness or precise muscular control.
3. Tasks which measure primarily central rather than peripheral neural processes such as reaction time, monitoring, and pattern recognition, are unaffected by vibration.

The effects of vibration on psychomotor tasks appear to be of a mechanical nature, i.e., mechanical forces produce interfering movements of the subject's arm. Also, vibration interferes with visual acuity thereby making the execution of any visually dependent response difficult. Therefore, tasks requiring no precise motor movements or visual acuity and which measure primarily central neural processes should be unaffected by vibration.

References

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Weisz, A. A., Goddard, C., and Allen, R. W. Human performance under random and sinusoidal vibration (AD 631 457; AMRL TR 65-209). Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, 1965.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Guignard, J. C., and Irving, A.

TITLE: Effects of low-frequency vibration on man.

CITATION: Engineering, 1960, 190, 364-367.

PURPOSE: The purpose of this study was to determine if vertical sinusoidal vibration degraded performance on a placing task, particularly at body resonant frequencies.

METHODOLOGY:

SUBJECTS: The subjects were four men.

EQUIPMENT: Vibration was imparted to the subjects via a shake table and platen chair without backrest or cushioning.

PROCEDURE: The subjects were unrestrained and posture was standardized. The displacement-amplitude of vibration was set to produce an acceleration of ± 0.25 g at the platen at all frequencies over the range 2.4 to 9.5 cps (explored in half-octave steps). The subjects did not spend more than four minutes under each vibration condition. The task, one of hand-eye coordination, required the subject to pick four markers off the periphery of a 16 inch diameter disk in front of him and place them precisely on spots (providing 1/32 inch clearance) one inch from the center of the disk. Performance was measured as the mean time taken from starting signal to completion of a number of replicates of each task. Performance was also measured under no vibration.

SIGNIFICANT RESULTS: On inspection, the results showed that performance was impaired at all frequencies of vibration, but an analysis of variance showed this impairment to be significant only at 3.4 and 4.8 cps ($p < .05$).

CONCLUSIONS/RECOMMENDATIONS: These findings support the hypothesis that vibration degrades performance particularly at frequencies which excite large differential movements within the body. Performance peaks occurred at a lower frequency than the peak of shoulder resonance and may be related to vertical-velocity of the head. Since the degradation of simple task performance at frequencies below 10 cps seems to be narrowly frequency-dependent, new aircraft, etc., must be designed to eliminate such frequencies. Since this is nearly impossible to achieve ad hoc methods of vibration control for the occupants is a necessity.

ENVIRONMENT: VIBRATION +1 Hz

AUTHOR: Harris, C. S., & Sommer, H. C.

TITLE: Interactive effects of intense noise and low level vibration on tracking performance and response time.

CITATION: Aerospace Medicine, 1973, 44, 1013-1016.

Studies conducted in our laboratory on the combined effects of noise and vibration on tracking performance have yielded both additive and subtractive effects. One reason for the difference in results may be the difference in the intensity levels of the noise used. Subtractive effects were obtained in a recent study using 100 dB noise while additive effects were obtained in another study using 110 dB noise. However, there were additional differences between the studies, other than noise level, that could have accounted for the results. The purpose of the present study was to determine whether the intensity differences in noise level can account for the results. Approximately the same procedures were used in the present study with 110 dB noise as were used previously in a study where a subtractive effect was obtained with 100 dB noise. The performance of 12 subjects was measured during two conditions of noise, 65 dB and 110 dB, and two conditions in which these noise exposures were combined with 0.10 g_z (vertical) vibration at 6 Hz. Noise produced a detrimental effect on tracking task performance and the effect was additive to the adverse effect produced by vibration when both noise and vibration were presented simultaneously. These results, along with the results of the previous experiments, demonstrate that as noise level is increased from 100 to 110 dB the combined effect of noise and vibration changes from subtractive to additive.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Hornick, R. J.

TITLE: Effects of whole-body vibration in three directions upon human performance.

CITATION: Journal of Engineering Psychology, 1962, 1, 93-101.

PURPOSE: The purpose of this study was to explore the effects of whole-body vibration in three directions on human performance in vehicle control.

METHODOLOGY:

SUBJECTS: The subjects for any particular study were 10-20 males between the ages of 18 and 26.

EQUIPMENT: A multi-directional shake table with a back supported chair was used to impart vibration to the subjects. Additional apparati were used to simulate an automobile driving situation.

PROCEDURE: Measures were taken on compensatory tracking ability, choice reaction time, foot pressure constancy, peripheral vision, and visual acuity. All measures except that of visual acuity were incorporated into a simulated driving situation. The subjects guided a blip on a scope by means of a steering wheel for compensatory tracking, attempted to maintain a constant foot pressure by means of a simulated accelerator and speedometer, choice reaction time was evaluated by responding to appropriate colored-light patterns by pressing a simulated brake pedal, and peripheral vision was evaluated by lights around him to which he responded by pressing the "horn". Visual acuity was measured in separate sessions with Landolt C's. Body equilibrium was measured before and after each vibration condition. Subjects were evaluated four times in each of 15 vibration conditions--five frequencies of 1.5, 2.5, 3.5, 4.5, and 5.5 cps, and three intensities--0.15, 0.25, and 0.35 g peak accelerations. The measures were taken before vibration (PRE), the first 15 minutes of vibration (V_1), the last 15 minutes of vibration (V_2), and following vibration (POST). Each experiment utilized a multivariate analysis of variance design with repeated measures.

SIGNIFICANT RESULTS: The results are summarized as follows:

Compensatory Tracking Ability--Vertical vibration caused a decrement in tracking ability with significantly ($p < .01$) incomplete recovery following exposure. For transverse

vibration greatest error decrement occurred at 1.5 cps. Increases in intensity caused error increases for both transverse and longitudinal vibration.

Choice Reaction Time--Reaction time was not impaired under any frequency-intensity combinations. However, a significant ($p < .01$) increase in response time was found during the POST period for the vertical and transverse conditions.

Foot Pressure Constancy--Vertical vibrations of 5.5 and 6.5 cps elicited significant decrements ($p < .01$) in constant foot pressure with increasing decrement accompanying increasing intensity ($p < .05$). With transverse vibration greatest decrement occurred at 1.5 and 2.5 cps ($p < .01$) with increasing decrement accompanying increasing intensity ($p < .01$). For longitudinal vibration 2.5 and 3.5 cps elicited greatest decrement ($p < .01$) with the same relationship holding for intensity and decrement ($p < .01$). In all cases recovery was complete following exposure.

Peripheral Vision--This was not studied with vertical vibration. During transverse vibration 1.5 and 2.5 cps elicited a significant ($p < .05$) loss in peripheral vision, though the decrement was not affected by intensity increases and was minute in magnitude (less than 1 degree). Longitudinal vibration had no effect on peripheral vision.

Visual Acuity and Body Sway--Visual acuity as measured with Landolt C's revealed no effects of low frequency vibration in any direction. Also, no change in body equilibrium was found.

CONCLUSIONS/RECOMMENDATIONS: These studies demonstrated that low frequency vibration similar to that experienced in vehicles can significantly impair human performance related to control of the vehicle. With respect to compensatory tracking ability, decrements increase as a function of vibration exposure duration with incomplete recovery afterwards. This finding has import in systems evaluation. Foot pressure constancy during vibration is a biomechanical function over which the subject has little control as evidenced by the fact that error increases with increased intensities. In general, these studies indicate that understanding the human component in a dynamic system requires more than the simulation of temperature, lighting, display, and auditory conditions. One must also simulate the dynamic aspects of mobile systems.

ENVIRONMENT: VIBRATION +1 Hz

AUTHOR: Hornick, R. J.

TITLE: Problems in vibration research.

CITATION: Human Factors, 1962, 4, 325-330.

Man's exposure to low-frequency vibration in vehicles is discussed. Research with humans in vibration experiments has led to a common core of findings, but with some areas of conflict. Discrepancies in results are examined in the light of several methodological problems. These are (1) procedural variations including use of subjects, body restraints, body supports, and constant amplitude vs. constant acceleration experimental designs; (2) terminology, with attention to directions of motion; (3) random vs. sinusoidal motion; (4) single and multiple factors; (5) scaling; and (6) performance evaluation including the matters of equipment set-up, vibrating and stable displays, and standardized tasks.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Hornick, R. J. and Lefritz, N. M.

TITLE: A study and review of human response to prolonged random vibration.

CITATION: Human Factors, 8, 1966, 481-492.

This article describes a study conducted to determine the effects of long duration, random vibration—characteristic of low-altitude high-speed (LAHS) flight aircraft—on human performance, physiological, biodynamic, and tolerance responses. Ten subjects experienced 0.10, 0.15, and 0.20 RMS g with a shaped power spectral density from 1 to 12 cps while engaging in LAHS control tasks. Simulation runs were of 5 hours duration, with the centermost 4 hours under dynamic conditions. Results of this experiment are related to those of other studies which had the same general objectives in order to provide a brief review and summary about what is known regarding human capabilities for LAHS flight.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: La Rue, M. A. Jr.

TITLE: The effects of vibration on accuracy of a positioning task.

CITATION: Journal of Environmental Sciences, 1965, 8, 33-35.

PURPOSE: The purpose of this study was to determine if a degradation in accuracy would occur in a positioning task at frequency levels of 5-22.5 cps.

METHODOLOGY:

SUBJECTS: No information was given concerning the subjects.

EQUIPMENT: Equipment utilized was a chair mounted on a shake table, a control stick, a CRT display, and two Hewlett Packard Model VTVM's--one to denote vertical error, the other horizontal.

PROCEDURE: Each subject established his "zero" between target spot and crosshair on the CRT under no vibration. The subject then displaced and recentered his target by moving his control stick. This was done 10 times in a no vibration condition and 10 times in a chosen frequency and g level condition--5, 7.5, 10, or 22.5 cps and 0.1, 0.2, or 0.3 g. This was followed by another no vibration condition and a five minute rest period. This procedure was repeated until all conditions of frequency and g level combinations were administered.

SIGNIFICANT RESULTS: No significant difference was found between the performance in the static environments before and after the vibration conditions. The average accuracies obtained for the frequency levels did not differ significantly under any combinations. However, the consistency with which this average value was obtained was analyzed and it was noted that significant differences in variability were obtained in the vertical plane for all g levels and in the horizontal plane for the 0.1 g level only. It was also noted that at the 0.1 g level horizontal positioning was most affected by 7.5 cps rather than 22.5 and 5 cps. No differences were found in the 10 cps conditions.

CONCLUSIONS/RECOMMENDATIONS: The fact that the major decrements occurred in the vertical plane of positioning was expected since the shake table vibrated only in the vertical plane. Little decrease in accuracy will occur if the operator is subjected to frequency levels in the

5-22.5 cps range. As long as frequency is kept above 5 cps at g levels of 0.1, 0.2, and 0.3 a positioning task can, on the average, be performed as accurately as in a no vibration environment. However, if consistent accuracy is required, this author recommended that man not be forced to work in frequency environments below 7.5 cps.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Schohan, B. Rawson, H. E., and Soliday, S. M.

TITLE: Pilot and observer performance in simulated low altitude high speed flight.

CITATION: Human Factors, 7, 1965, 257-265

Responses of experienced pilots and aerial observers were studied in simulated low-altitude, high-speed (LAHS) flight.

The pilots "flew" three-hour surveillance missions at airspeeds of .4M and .9M in different degrees of simulated atmospheric turbulence. Flying ability decreased from .4 to .9M; however, intensity of vertical accelerations did not seem to affect flying ability except at the most severe levels. Target identification was unimpaired by either turbulence or airspeed.
The observers also flew three-hour missions while experiencing acceleration time histories recorded from the pilot's flights. Target identification deteriorated as airspeed increased from 0.4 to 0.9 Mach. Gust intensity did not affect performance of any of their tasks. Performance efficiency on all tasks did not deteriorate from beginning to end of the missions of both pilots and observers.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Shoenberger, R. W.

TITLE: Effects of vibration on complex psychomotor performance.

CITATION: Aerospace Medicine, 38, 1967, 1264-1268.

Human performance was measured on a complex of three psychomotor tasks, during short duration (30 minutes) vertical sinusoidal vibration (seated subject, $+1G_z \pm nG_z$) at peak accelerations of $\pm.20G_z$, $\pm.25G_z$, and $\pm.30G_z$ at 5 cps; $\pm.25G_z$, $\pm.30G_z$, and $\pm.35G_z$ at 7 cps; and $\pm.30G_z$, $\pm.45G_z$, and $\pm.60G_z$ at 11 cps. The tasks ("target identification," "probability monitoring," and "warning-lights monitoring") had relatively small motor components and were largely "mental" or intellectual in nature. The results provided very little evidence of decrement on these tasks as a result of vibration. Previous studies employing a two-dimensional tracking task showed significant decrements at .20G at 5 cps, .25G at 7 cps, and .37G at 11 cps. This previous task required a high degree of manipulative skill and was therefore more susceptible to direct mechanical interference from the vibration. These results, plus the fact that the greatest mechanical response of the human body occurs in this low frequency range, suggests that direct mechanical interference with the motor aspects of the task may be the most significant factor contributing to performance decrements during relatively low intensity short duration vibration.

ENVIRONMENT: VIBRATION +1 Hz

AUTHORS: Shoenberger, R. W

TITLE: Human performance as a function of direction and frequency of whole-body vibration.

CITATION: (AMRL-TR-70-7). Final Report, Wright-Patterson Air Force Base, Ohio, October 1970.

PURPOSE: This study investigated the effects of sinusoidal vibration in each of the three major axes on two-dimensional compensatory tracking and visual discrimination reaction time.

METHODOLOGY:

SUBJECTS: The subjects were 22 male Air Force military personnel. Ten subjects were used in each of the three axis vibration conditions.

EQUIPMENT: A mechanical shake table with an unpadded seat and backrest was used. Subjects were restrained by a lap belt and shoulder harness. A CRT mounted on the work station provided the stimulus for the tracking task with three red and three green lights mounted in a row below it providing the stimuli for the reaction time task.

PROCEDURE: Performance was measured in each axis at frequencies of 1, 3, 5, 8, and 11 cps at peak accelerations of 0.2 and 0.4 g. The duration of vibration at each frequency was nine minutes. For the tracking task the subject was to keep a light in the center of a crossbar on the CRT. For the visual reaction time task the subject monitored the row of lights and pressed a button if any of the green lights went off or a red light came on. A separate experiment was conducted for each of the three axes of vibration (X, Y, and Z). Two groups of five subjects each served in each experiment. For each axis one group received vibration at each of the five frequencies at 0.2g and the other group at 0.4g. All subjects practiced the task with no vibration for eight four minute trials for two sessions. During the third training session each subject received four trials of practice without vibration, tow trials at 7 cps, and two trials at 2 cps. The intensity for these practice trials was either 0.2 or 0.4g, depending upon the group to which the subject belonged. In each testing session the subject received an initial warm-up trial with no vibration and then two test trials during each of the three experimental conditions presented that day. All trials were four minutes long with a one minute intertrial interval for recording scores.

SIGNIFICANT RESULTS: The results were as follows:

(1) Vibration in the Y axis produced considerably more decrement in horizontal tracking performance than in either of the other two axes. This effect was especially pronounced for the three lowest frequencies.

(2) Vertical tracking performance suffered greater decrement at 1 and 3 cps in the Y axis than in the X or Z axes.

(3) X and Z axis vibration produced greater increases in vertical error than in horizontal.

(4) Y axis reaction time showed greatest decrement at 1 and 3 cps.

(5) X and Z axes reaction times were insignificant by frequency or g level.

CONCLUSIONS/RECOMMENDATIONS: All performance measures exhibited greatest decrements for Yaxis vibration at 1 and 3 cps. This is in agreement with data on body resonance effects. Differential frequency effects were less pronounced for the X and Z axes. In terms of overall performance effects for the X and Z axes the most decrement occurs around 5 cps, with the X axis decrement being slightly greater than the Z axis. The very large decrements in Y axis vibration can be partially attributed to the inefficient seating and restraint system used. It was suggested that specialized support and limb restraint (as well as torso) would improve performance.

FINAL CONCLUSIONS

Many problems exist in drawing final conclusions about performance as affected by environments which produce such diverse stimuli as the ones examined in this report. The danger lies in over-generalizing performance effects across environments so as to produce a definitive conclusion. Unfortunately, nature is seldom simple and rarely presents clearcut answers to questions. Such is the case regarding the present environments.

In general, psychomotor performance mediated by central processes (i.e. reaction time, vigilance, etc.) is relatively unaffected by hyperbaric/underwater, thermal, or vibratory environments. Psychomotor factors involving tasks mediated by peripheral processes (i.e. manual performance, tracking, fine control sensitivity, etc.) tend to show decrements in these environments ranging from mild to severe depending upon the specific task and environment involved. It is cautioned that these are extremely broad gneeralizations and may not apply in every case.

The underlying causes of psychomotor performance degradation in the environments considered seem to fall into two broad categories: (1) Mechanical and/or Physiological causes (2) Psychological Stress. The first of these involves stimuli which cause a mechanical or physiological interference with psychomotor performance. Examples would be the mechanical interference of vibration with a tracking

task or the physiological interference of cold with manual dexterity.

The second cause involves what Teichner (1954) called "psychological stress". This type of task interference is psychological rather than physical. An example would be the interference of cold with a manual dexterity task due to the extreme unpleasantness or pain induced by the cold.

Neither of these possible underlying causes is mutually exclusive of the other in its effects on performance. They can and frequently do act in either an additive or synergistic fashion to produce performance decrements.